This thesis studies some of the links coupling the social and ecological components n a Social-Ecological System (SES) on the coast of East Africa. It does so by assessing the return of ecosystem goods and services in restored mangroves through both ecological and socio-economic measurements, and by empirically studying variations and diversity in content of local ecological knowledge among resource users, its relation to valuation of ecosystem goods and services and its distribution across a social network.

Taking its starting point in a study of the return of ecological functions in restored mangroves (Paper I) the main results of the thesis are presented in three sections. The ecological perspective showing restored mangroves as nursery grounds for juvenile shrimp communities is complemented by findings from interviews with local user groups revealing a range of ecosystem goods and services associated with natural and replanted forests (Paper II). The thesis moves on to show heterogeneity in local ecological knowledge held by groups of resource users (Paper III) and how this can be correlated with structure of the social network for transferring such information and knowledge (Paper IV). This network structure is elaborated upon in the third and final section to look at the role it might play for community social capital and for structurally well positioned individuals to access such capital and initiate collective action for natural resource management (Paper V). The role played by social capital in shaping the informal institution represented by middlemen in the study area is also touched upon as is the function of middlemen in linking social and ecological dynamics of the coupled Social Ecological System (Paper VI). Finally, the implications of these findings are discussed in the context of natural resource management with focus on co-management and community involvement.

Department of Systems Ecology,
Stockholm University 2006

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OF MANGROVES AND MIDDLEMEN

A study of social and ecological linkages in a coastal community

Beatrice
Crona

Of Mangroves and Middlemen

A study of social and ecological linkages in a coastal community

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Doctoral Thesis in Marine Ecotoxicology

Department of Systems Ecology
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To the people of Gazi…

…and to Mom

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

- T.S. Elliot, "Little Gidding" in Four Quartets.

Abstract

This thesis studies some of the links between the social and ecological components in a coastal Social-Ecological System (SES) of East Africa to gain insight into factors affecting natural resource management at a community level. It does so by assessing the return of ecosystem goods and services in restored mangroves through both ecological and socio-economic measurements, and by empirically studying variations and diversity in content of local ecological knowledge among resource users, its relation to valuation of ecosystem goods and services and its distribution across a social network.

Taking its starting point in a study of the return of ecological functions in restored mangroves (***Paper I***) the main results of the thesis are presented in three sections. The ecological perspective showing restored mangroves as nursery grounds for juvenile shrimp communities is complemented by findings from interviews with local user groups revealing a range of ecosystem goods and services associated with natural and replanted forests (***Paper II***). The thesis moves on to show heterogeneity in local ecological knowledge held by groups of resource users largely related to the method of resource extraction (***Paper III***) and how this can be correlated with structure of the social network for transferring such information and knowledge (***Paper IV***). This heterogeneity of knowledge is also discussed in relation to the range and value of ecosystem goods and services provided by mangroves as perceived by local user groups. The social network structure is elaborated upon in the third and final section to look at the role it might play for community social capital and for structurally well positioned individuals to access such capital and initiate collective action for natural resource management (***Paper V***). The paper explores possible explanations why the community in focus has not been successful in regulating the inshore local fishery which has led to a system currently diagnosed as overexploited. Results suggest that poor problem internalization (i.e. recognition of overexploitation as a potential threat to future livelihoods) among influential individuals may significantly affect agency and this may occur in spite of combination high levels of ecological knowledge within a group if personal identification with an area is not prevalent.

The role played by social capital in shaping the informal institution represented by middlemen (fishmongers) in the study area is also touched upon as is the function of middlemen in linking social and ecological dynamics (***Paper VI***). Finally, the implications of the findings of the thesis are discussed in the context of natural resource management with focus on co-management and community involvement.

Reflections

Including a section like this may be unconventional yet I feel it serves a purpose in describing the process of development and change – personal, but reflected in research- which is so much the essence of the research and PhD process. I feel strongly that this thesis has been a journey, as cliché as it may sound. A journey through different ways of thinking, theories, ideas and even disciplines. And in the end this scientific and inter-disciplinary journey became one of personal development. From the person I thought I was, a natural scientist who liked to think in terms of experimental design, proving hypothesis and who thought ecology was great because nature never asked you questions back, to someone who is still frighten by the unpredictability of people in many ways but also fascinated by their relations and interactions and how these patterns affect myself and others. Many people have contributed to the insights, new ideas and impressions that made up this journey. From family, friends and colleagues to supervisors and other wise and insightful persons I have been lucky enough to meet during the course of these five years. To all of you an enormous THANK YOU. You have given me so much. I only hope that in the process I was able to give you all something little in return.

Always running the risk of leaving someone out, unintentionally, some people still deserve a special mention:
My mother, for supporting me no matter what and for always providing a safe haven somewhere in the world, when responsibilities have seemed too much at times.
My supervisors, Patrik Rönnbäck and Nils Kautsky for believing in me enough to take me onboard and giving me a shot at doing research. I never pictured myself doing a PhD…
My friends (you know who you are), for always being there, through ups or downs, taking my mind off work and keeping me company in everything from snowboarding to finishing off those half-empty bottles in the cupboard to leave room for new, full ones!. And not to be forgotten, for putting up Otis the Cat during my endless thesis-related travels.
My colleagues (and co-authors), Örjan Bodin for making thesis work after my Licentiate fun again and always challenging my thoughts, Örjan B and Henrik Ernstsson for fun and inspiring network discussions, HE again for valuable help on making this 'Kappa' intelligible, Per Olsson for lending an ear which gave me the courage to dive into the world of LEK, Magnus Nyström for inspiration pretty much every time we meet, Patrik Rönnbäck for meticulously reading everything I send you and always giving me feedback, Maricelita for venting frustrations and hopes with, Carl Folke for always saying I had potential…after five years I'm almost starting to believe it! Jon Norberg, Maria Tengö, Thomas Elmqvist, Thomas Hahn, and everyone else in the NRM group for great discussions and for providing such an inspiring environment to work in. To Christina Schaffer, Cajsa Martinsson, Lousie Hård and the rest of The Manna and CTM Team for contributing to make my 20% non-research an inspiration to my research and my life in general. A special thanks to Christifina and Calle for giving me the opportunity to become part of the CTM work way back in the days… It has broadened my scope and made me a more *functionally diverse and resilient person*!! Thanks also to Christina Danielsson for help with layout and design.

To all my friends and colleagues at KMFRI (Bosire, Kairo, Mwangi, Kimani, Mwatha, Jacqui, Gwatha, the technical staff and everyone else) thank you for all your help and for making my work in Kenya so memorable. To all my friends in Gazi and Mombasa (Abdul, Hafsa, Hamisi, Bakari, Rashid and Kimani among many others) – thank you for your help and support and for making Gazi a home away from home.

Thank you all! I could not have done it without you.

Stockholm
May 26, 2006

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numeral:

I Crona, B.I. and Rönnbäck, P. (2005) Utilization of replanted mangroves by postlarval and juvenile shrimps in Gazi Bay, Kenya. *Estuarine Coastal and Shelf Science* 65:535-544.

II Rönnbäck, P., Crona, B.I. and Ingwall, L. The return of ecosystem goods and services in replanted mangrove forests – Perspectives from two local communities in Kenya. (Manuscript)

III Crona, B.I. (2006) Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. *Ecology and Society* 11(1): art 32.

IV Crona, B.I. and Bodin, Ö. (2006) WHAT you know is WHO you know? Communication patterns among resource users as a prerequisite for co-management. *Ecology and Society*, *accepted for publication*

V Bodin, Ö. and Crona, B.I. Community-based management of natural resources – the role of social capital and leadership in a rural fishing community. (Manuscript)

VI Crona, B.I., Nyström, M., Mogren, J., and Folke, C. Middlemen as critical links in Social-Ecological Systems: An example from fishing communities in Eastern Africa. (In review *Environmental Conservation*)

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My contribution to the papers included in the thesis is as follows:

I, III Responsible for all field work, data analysis and lion part of writing.
II Involved in project design, supervision of student collecting field data, and writing.
IV, V Responsible for all field work and certain sections of data analysis. Both authors contributed to the writing.
VI Responsible for all Kenya field work and data analysis, and lion part of writing.

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Swedish summary / Svensk sammanfattning

Sett ur ett historiskt perspektiv har människan alltid varit beroende av naturen för sin överlevnad och i vår strävan att ständigt förbättra våra livsvillkor har vi samtidigt haft en stark, och ibland förödande, påverkan på många av jordens ekosystem. Men naturen påverkar i sin tur människor genom sin förmåga att leverera varor och tjänster samt, under extrema förhållanden såsom naturkatastrofer, genom akut påverkan på de samhällen vi byggt upp. För att belysa detta starka dubbelriktade beroende har forskare på senare tid utvecklat konceptet Social-Ekologiska System (SES) vilket syftar till att tydliggöra länkar mellan samhället och naturen och visa på hur dessa återkopplingar verkar. Denna avhandling grundar sig på ovan nämnda synsätt och belyser ett urval av just sådana kopplingar mellan samhället och naturen utifrån i huvudsak ett fallområde i södra Kenya. Fokus ligger på kopplingar mellan natur och samhälle vilka påverkar resursutnyttjande och förvaltning i kustzonen.

Avhandlingen inleds med en studie av hur väl en ekosystemtjänst, nämligen den som yngelkammare för kommersiellt viktiga räkarter, kan anses ha återetablerats i återplanterad mangrove (***Papper I***). Mangrove är en, globalt sett, hotad miljötyp och i Östafrika har dessa kustskogar framför allt hotats av timmeravverkning. Vissa försök har gjorts runt om i världen för att återplantera mangrove men få av dessa planteringar har utvärderats för att uppskatta ekosystemtjänster och varor annat än de som är direkt kopplade till träden, såsom timmer och i viss mån erosionsskydd. Studien visar att tjänsten som yngelkammare i viss mån kan anses återetablerad sett ur ett rent ekologisk perspektiv. Detta naturvetenskapliga synsätt kompletteras i ***Papper II*** genom att via intervjuer med lokala resursutnyttjare kartlägga deras syn på varor och tjänster associerade till mangrove generellt, deras syn på hur väl dessa tillgodoses av återplanterade områden samt en analys av hur olika grupper av resursutnyttjare uppfattar varor och tjänster beroende på yrke, kön och fysiskt närhet till resursen. Nästa studie i avhandlingen (***Papper III***) bygger på samma indelning av resursutnyttjare men ökar upplösningen av dessa grupper för framförallt fiskare och går vidare för att mer grundligt undersöka hur den lokala ekologiska kunskapen (LEK) om det sammantagna kustlandskapet (mangrove, sjögrässängar och korallrev) ser ut samt om den skiljer sig mellan grupper. Resonemanget grundar sig i antagandet att kunskap om hur de lokala ekosystemen fungerar och är kopplade till varandra är en förutsättning för att bättre kunna värdera de varor och tjänster de tillhandahåller. Vissa skillnader i kunskap mellan grupperna påvisas och en diskussion förs kring vilka faktorer som orsakar detta mönster. En sådan faktor är det sociala nätverk som används av invånarna i byn för att utbyta information och kunskap om naturen. Detta nätverk kartläggs i ***Papper IV***. Dess struktur jämförs med mönstret av kunskap mellan grupper i ***Papper III*** i ett försök att påvisa hur sociala nätverksstrukturer kan spela roll för att förstå hur kunskap byggs upp och sprids. Studien visar även att vissa grupper är mer centrala än andra och diskuterar, utifrån gruppernas skiftande karaktärer vad gäller yrke, lokalkännedom och probleminsikt, hur detta kan påverka samhällets förmåga att nå konsensus kring resurshanteringsproblem och därigenom även gemensamma initiativ för förvaltning. ***Papper V*** fortsätter analysen av sociala nätverk genom att identifiera ett antal centralt positionerade individer (här kallade nyckelindivider) och undersöka deras syn på ledarskap. Socialt kapital mäts genom en kombination av nätverksbaserade mått samt befintliga strukturer för konflikthantering. Utifrån teorier om sociala nätverksstrukturer, socialt kapital och ledarskap diskuteras sedan bristen på initiativ till samförvaltning i fallområdet.

Avhandlingen avslutas med en studie med mer regionalt fokus (***Papper VI***). I denna görs en analys av den roll som fiskhandlare (eng 'middlemen') har i det småskaliga fisket längs med Kenya och Tanzanias kust och hur socialt kapital till viss del utgör en förutsättning för denna. Pappret beskriver den viktiga länk fiskhandlarna utgör mellan det sociala och det ekologiska

systemet genom att fungera som finansiärer av småskalig resursexploatering och på så vis påverka dynamiken i såväl det socioekonomiska som det naturliga systemet.

Introduction

Throughout history humans have shaped nature which in turn has shaped human societies (Redman 1999; Jackson *et al.* 2001). This reciprocal influence from resource-use and ecological feedbacks depicts the interdependency and interconnectedness that exists between social and ecological systems (Folke 2006). The concept of coupled social-ecological systems (SES) thus emerged in an effort to make the linkages between the human and ecological components more explicit, as well as focusing on the feedback mechanisms by which the two are coupled (Berkes & Folke 1998; Folke *et al.* 2005). Four factors have been identified as critical for SES to deal with ecosystem dynamics during periods of change and reorganization, these include; learning to live with change and uncertainty, nurturing diversity for reorganization and renewal, combining different types of knowledge for learning, and creating opportunities for self-organization toward social-ecological sustainability (Folke *et al.* 2003). This thesis attempts to look at some of the links between the social and ecological components of a coastal SES and addresses the above listed critical factors by empirically studying variations and diversity in content of local ecological knowledge among resource users, its relation to valuation of ecosystem goods and services and its distribution across a social network (Figure 1). It also looks at how social network structure can help identify formal and informal leaders while also speculating on the role of these leaders for co-management and collective action related to management of natural resources.

There are many approaches to governance of natural resources, where co-management is one form, emphasizing sharing of power and inclusion of local stakeholders in decision making (Singleton 1998; Carlsson & Berkes 2005). Yet definitions of co-management have often encountered difficulty in capturing the complexities and dynamic nature of contemporary governance systems arising from heterogeneity within the state, communities, and the natural systems to be managed (e.g. Carlsson 2000; Carlsson & Berkes 2005). This thesis looks at how heterogeneity among stakeholder may affect knowledge distribution between groups and how this in turn affects perceptions and valuations of ecosystem services. It also treats some aspects of heterogeneity of the natural resource itself by looking at distribution of juvenile shrimp in the mangrove ecosystem as well as assessing variation in the goods and services provided by mangroves to the local communities (Figure 1).

Taking its starting point in a study of the return of ecological functions in restored mangroves, the main results of the thesis are presented in three sections. The ecological perspective showing restored mangroves as nursery grounds for juvenile shrimp communities is complemented by findings from interviews with local user groups revealing a range of ecosystem goods and services associated with replanted forests. The second section moves on to show heterogeneity in local ecological knowledge (LEK) held by groups of resource users and how this can be correlated with structure of the social network for transferring such information and knowledge. This network structure is elaborated upon in the third and final section to look at the role it might play for community social capital and for structurally well positioned individuals to access such capital and initiate collective action for natural resource management. The role played by social capital in shaping the informal institution represented by middlemen (fishmongers) in the study area is also touched upon and the linking function of middlemen, between the ecological and social components of the SES, is discussed. Finally, the implications of

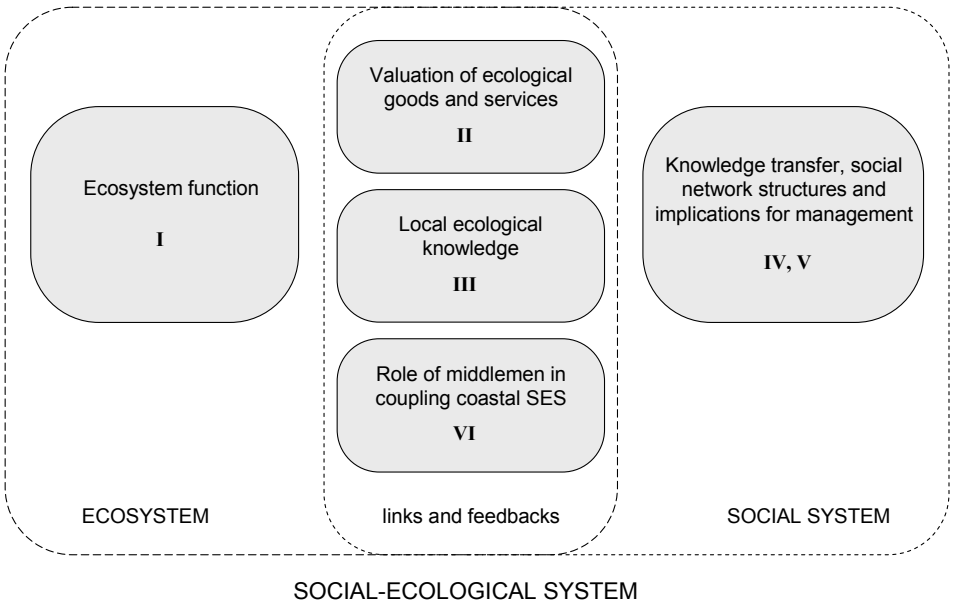

Figure 1. A schematic representation of a linked Social-Ecological System (SES), showing the ecological component, the social component and the interphase at which links and feedback mechanisms operate. The papers of the thesis are inserted to show the specific issue in focus of each respective study, while also providing an overview of how each paper relates to the general framework of social-ecological systems.

these findings are discussed in the context of natural resource management with focus on co-management and community involvement. The overarching goal of the thesis is thus to identify factors affecting natural resource management at the community level by focusing on some of the different aspects listed above and relating them to the level of success of resource management in the case community. This is of crucial importance at a time when coastal tropical resources are being increasingly decimated at alarming rates.

Scope of the thesis

Ecosystem management, democratic governance, and poverty reduction are identified by the World Resource Institute as three essential elements of sustainable economic growth (WRI 2005). These elements are inextricably linked and dependence for livelihood on natural resources is greatest among the rural poor of the world. Marine fisheries are particularly important for the livelihood of many coastal communities and over 90 % of the 35 million people working the world's coastal waters are small-scale fishermen (Kura *et al.* 2004). At the same time many coastal resources available to these communities are being gradually degraded by over-use and exploitation and resilience of social and ecological systems is linked through the dependence of communities on ecosystems for their economic activities and well-being (Adger 2000). Exemplified here through coastal communities, it thus seems humanity is facing a great challenge; to manage our natural resources such that the capacity of ecosystems to

produce goods and services is maintained while also ensuring an equitable distribution of environmental benefits to secure social welfare.

This thesis addresses this challenge by increasing our understanding of the links between the social and ecological systems operating in a coastal community. It uses a case study approach, focusing on a rural fishing community in East Africa, and different aspects of the issue are addressed in the six scientific papers which make up the thesis. The thesis begins by describing the return of ecosystem function in replanted mangroves of the area (***Paper I***), with specific focus on the important ecosystem service of nursery grounds for shrimps provided by mangroves to the coastal fishery. The mangroves were replanted in an effort to restore areas degraded by excessive timber extraction. The thesis then proceeds to investigate how local user groups perceive and value the return of ecosystem goods and services in these replanted mangroves while also comparing them, in this respect, to natural, less impacted forests (***Paper II***). However, the ability of users to value a resource is closely related to their knowledge about the ecology of the ecosystem providing the goods and services to be valued. Although knowing the ecology behind the production of a certain good or service may not affect the valuation of the product itself it will increase the perceived value of maintaining the ecosystem behind the production of it. In addition, I argue that the greater the understanding of ecological links and processes related to the ecosystem at hand, the greater the chance that resource users will acknowledge a broader number of goods and services. ***Paper III*** therefore sets out to investigate the local ecological knowledge (LEK) held by different user groups in the community and whether this knowledge differs between groups.

A management system that embraces adaptability and explicitly puts forth the importance of resource users' localized ecological knowledge is embodied in the concept of adaptive co-management (Gadgil *et al.* 2000). Yet a reasonable level of consensus and mutual understanding of resource status is essential to increase the likelihood that stakeholders will be able to organize and agree upon common rules on how to manage their natural resources (Ostrom 1990). Hence, exchange of information and knowledge among stakeholder groups emerges as a fundamental element of successful governance in this respect. These issues are examined in ***Paper IV*** which looks at the social networks for communication of resource related knowledge and information within the community and links this to the distribution of LEK found in ***Paper III***. ***Paper V*** builds on the network approach and uses it to study issues of social capital, agency and collective action. The paper looks at potential explanations as to why collective action for common pool resource (CPR) management has not occurred in a community despite strong indications of declining fisheries and recognition of this by community members dependent on the resource. Agency is approached from a social network perspective using structural network measures to identify key individuals and social capital is estimated based on a combination of relevant network characteristics and qualitative and quantitative interview data.

The final paper in the thesis (***Paper VI***) moves beyond the local to a regional perspective and looks at the role of middlemen (fishmongers) in East African rural fishing communities. The paper argues that middlemen, as buyers of fish from local fishermen, constitute a critical link between the social and ecological system in small-scale fisheries. This group of professionals link resource extractors and local markets directly, and through their role as informal micro-financing institutions they also affect seasonal fluctuations in fishing pressure. ***Paper VI*** evolved as a result of information emerging during data collection for the previous papers and can, in a sense, be viewed as a an attempt to conclude the thesis by refocusing on the links between the social and ecological systems in this seascape context and the feedback dynamics they give rise to.

Methods

The methods used in this thesis range from ecological fieldwork producing quantitative data in ***Paper I*** to individual and focus group interview methods in ***Papers II-VI***. ***Papers IV*** and ***V*** also make use of Social Network Analysis, described in more detail below.

Study area

The main study area includes a rural fishing community and the adjacent seascape, in turn comprised of mangroves, seagrass beds and fringing reefs. The area is located on the southern coast of Kenya (Figure 2), approximately 50 km south of Mombasa, and the inner estuary is sheltered from intense wave impact by shallow reefs at the mouth of the bay. Seasonal rains dominate the climate with two pronounced rainy seasons; a period of heavy rains from April-June (South East monsoon) and a period of lighter rains from October-November (North East monsoon).

A significant portion of the local mangroves were subject to overexploitation and clear-felling under commercial logging practices in the 1970's (Abuodha & Kairo 2001). In 1994 natural regeneration of mangroves had still not occurred in many sites and as a result planting was initiated through the Kenya Marine and Fisheries Research Institute (KMFRI). These

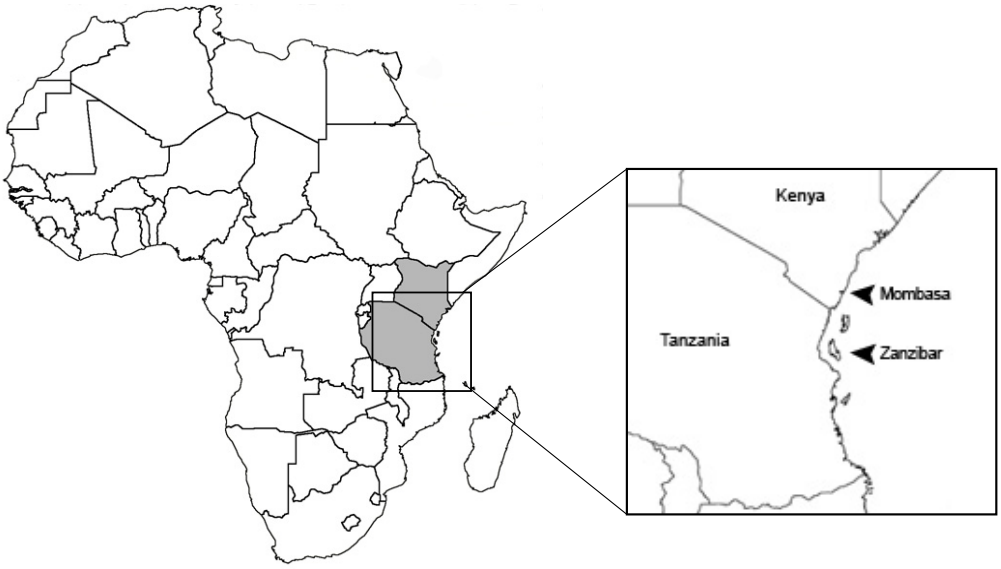

Figure 2. Study area and region. The main area of focus is located on the south Kenyan coast, approximately 50 km south of Mombasa (***Papers I-V***). Zanzibar is included in the final paper (***Paper VI***) to expand the focus of the thesis.

replanted plots (along with plantations initiated in 1998) form the basis of studies in ***Papers I*** and ***II***, and are compared with natural mangroves and a previously forested but now denuded area. The two plantations differed with respect to the method of planting used. The matrix plantation was planted on a clear-cut strip of fringing mangrove in a 1x1 m matrix, which has resulted in a dense monostand of *Sonneratia alba* with relatively high degree of canopy cover and a more homogenous root complexity throughout the site than the integrated plantation. The latter site was planted in a degraded but partly forested area adjacent to a natural stand of *S. alba*. Consequently, this site had a more heterogeneous appearance with natural canopy gaps and a higher variability in root complexity due to the diversity in age of the existing trees.

The village has approximately 200 households and an estimated 1000 inhabitants. The use of resources in the village is centered around fishing and to some degree the use of mangroves for poles and firewood. Other non-forest products are also taken from mangroves but government restrictions in the form of a cutting ban has periodically impeded extraction of wood products by locals (Dahdouh-Guebas *et al.* 2000). A majority of households depend primarily on fishing for their livelihood. The area has received a significant amount of immigration by fishermen from neighboring Tanzanian islands but also from inland areas. This influx of newcomers has put a strain on the traditional management system of marine resources (Glaesel 1997). Gradual weakening of traditional governance structures coupled with a national top-down view of legislation with heavy focus on regulatory measures but without sufficient capacity for enforcement (GOK 1991, 2001) has led to a situation where the inshore fishery along the southern Kenyan coast is a virtually open access system (Alidina 2005). This, in turn, has led to over-fishing and depletion of inshore stocks (Ochiewo 2004).

Paper I

This paper used stake nets to obtain quantitative measurements of shrimp density in mangrove habitats. The method was first developed by Vance (1996) (with reference to block net sampling of fish by Thayer(1987)) and later modified by Rönnbäck (1999) and Rönnbäck *et al.* (2001). The method employed in this study is the one described in Rönnbäck *et al.* (2001). Net pens measuring 3 x 3 m, thus enclosing 9 m^2, were set using four corner poles and the lower end of the net was secured in the mud. At high tide the nets were raised and catch was collected the following low tide. All nets had a stretched mesh size of 2 mm. Sampling was conducted on spring tides, all nets deployed at night, around maximum high tide, and catch collected at dawn as the tide receded. Two sites were always sampled simultaneously with four nets deployed in each site. All sites were sampled on each spring tide, and when consecutive spring tides were sampled the order in which the sites were sampled was switched for the second sampling occasion so as to avoid any bias from two sites always being sampled on the first days of the rising spring tide.

Papers II and III

Both papers made use of semi-structured interviews to collect data on the return of ecosystem goods and services in replanted mangroves, as perceived by local user groups (***Paper II***) as well as to study the local ecological knowledge (LEK) related to the entire seascape held by groups of resource users (***Paper III***). In both studies user groups were largely defined by their primary occupation (as defined by respondents), i.e. polecutters, fishermen, farmers etc, but ***Paper II*** also differentiates between genders. ***Paper II*** is based only on individual interviews while ***Paper III*** makes use of both individual interviews and replicated focus group interviews (Morgan 1988) to discern whether differences in LEK do exist between different groups. In ***Paper III*** knowledge was divided into three categories based on the three recognized sub-

components of the coastal seascape; mangrove, seagrass and reef. Amount of knowledge, for each occupational category, was analyzed and ranked based on the expressed level of detail of ecological components and processes. For a more detailed description, see Appendix 1 (***Paper III***).

Papers IV and V

Social networks have been studied from several different perspectives; from whole networks of communities, to personal networks of individuals or policy networks and networks of organizations. Consequently the methods also range from looking at social relations of a specific person (ego) (Burt & Minor 1983) to using network metrics to study general network characteristics, structural positions and tendencies for group formation (see for e.g. Granovetter 1973; Freeman 1979; Wellman 1988; Newman & Girvan 2004). Social Network Analysis (from now on referred to as SNA) originated out of the structural concerns of anthropologist Radcliff-Brown and is the study of social relations among a set of actors (Scott 2000). While other social sciences are often concerned with individual, monadic, attributes like income, age, sex, etc., network analysis focuses on (dyadic) attributes of pairs of individuals, such as 'knows', 'talks to' or is 'related to'. This thesis makes use of SNA in analyzing whole networks and employs a number of network metrics to discern structural patterns. The metrics include degree centrality, betweenness, eigenvector centrality and modularity, among others (e.g. Wasserman & Faust 1994; Scott 2000).

Paper IV maps the interaction patterns relating to the exchange of information and knowledge of natural resources among individuals in the community using SNA (e.g. Wasserman & Faust 1994; Scott 2000). This provided a toolbox to quantify various theoretically important structural characteristics of the social network. Social network data was gathered through use of oral interviews with questionnaires, in Kiswahili, and both attribute (income, occupation, age etc) and relational data (ties to other members of the community) were collected.

In ***Paper V*** the same SNA methods were used to identify leaders and to estimate social capital using a network approach described by e.g. Borgatti *et al.* (1998) and Lin (1999). Social capital, in the form of embedded resources, is thus captured by identifying relevant structural patterns and positions in the network.

Paper VI

This paper draws on data collected during fieldwork for the preceding ***Papers III-V*** and therefore uses combined methods of individual interviews and attribute data collected through social network questionnaires. It also makes use of additional interviews wqith middlemen in Kenya, as well as individual and group interviews from another study area on Zanzibar, Tanzania (Figure 2) and combines the two datasets for analysis.

Mangroves and human dependence on coastal resources

With the goal of identifying factors affecting natural resource management at the community level the following discussion will attempt to highlight the main findings of the individual papers and relate these to the overarching issue through a discussion of relevant theories.

Mangrove forest are some of the most threatened tropical ecosystems in the world with a global loss exceeding 35% of the original cover (Valiela *et al.* 2001; Alongi 2002). Countless studies have identified these coastal forests as vitally important for coastal communities as well as larger-scale economic activities of whole nations (Ruitenbeek 1994; Costanza *et al.* 1997; Rönnbäck 1999). Key functions of mangroves include their role in coastal protection and as nursery grounds supporting capture fisheries production (Ruitenbeek 1994; Ewel *et al.* 1998; Rönnbäck 1999). The former function became evermore obvious as catastrophic waves ravaged South East Asian coastlines during the 2004 tsunami. Yet the role of mangroves in coastal fisheries worldwide cannot be overly emphasized (for review see e.g. Baran & Hambrey 1998; Rönnbäck 1999), particularly for small-scale artisanal fishing communities subsisting on collection of both fish and shellfish associated with mangroves. This is supported by figures showing median fishermen densities of approx. 5.6 fishermen per km^2 in mangroves environments, figures which are considerably higher compared to other fished areas in terms of both fishermen density and yield per unit area (Matthes & Kapetsky 1988). In Indonesia, small-scale fishers are responsible for almost 95 % of total marine catch (FAO 2000) and in West Africa small-scale fishing contributes around 75 % of the region's total fish catch (Kura *et al.* 2004). Thus, the importance of artisanal fisheries for the livelihood of rural communities is evident, as is their consequent dependence on mangrove ecosystem services for stock recruitment and maintenance (e.g. Ewel *et al.* 1998; Rönnbäck 1999 for review).

Mangroves – an ecosystem under pressure

In spite of their documented importance, the last decade witnessed a continued decline in the estimates of mangrove coverage from 18 million hectares (ha), in the 1990's, to 15 million ha in 2000 (Valiela *et al.* 2001; Alongi 2002; Primavera 2005). The main causes of degradation and deforestation are anthropogenic in nature. Burgeoning populations, overexploitation of mangroves and conversion of mangroves to settlements, rice fields, salt beds, tourist resorts, and industrial facilities are some of the primary causes of mangrove degradation (Semesi 1998; Primavera 2005). But clearing for timber and wood-chips industry and excessive extraction of timber for firewood has also lead to the degradation of extensive habitats (Ong 1995; Field 1996; Semesi 1998; Hogarth 1999), as has the continued expansion of intensive aquaculture. In the Philippines alone half of the 279,000 ha of mangroves lost between 1951 and 1988 were developed into aquaculture (Primavera 2000) and a similar pattern can be found in other parts of Asia and South America (Rönnbäck 2001). To date Eastern Africa has been spared from large-scale aquaculture development but developers are moving in (Semesi 1998). This is an alarming trend, considering the lessons of social and environmental problems already learned from decades of shrimp farming in South East Asia.

In response to the increased decimation of mangrove forests, several rehabilitation programs have been initiated throughout the world (Saenger & Siddiqi 1993; Benthem *et al.* 1999; Imbert *et al.* 2000) and the need for mangrove preservation has started to be recognized as a high priority in local coastal management plans for many developing countries (Sloan & Sugandhy 1994; Lindén & Lundin 1996). The term ecological restoration, as defined by Jackson *et al.* (1995) is "the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems". This kind of restoration has only recently received attention (Lewis 1999). Earlier mangrove restoration goals have ranged from supply of quality wood (with the

ultimate goal of continued logging) to shore-line stabilization often overlooking the role of mangroves as habitats for a diverse flora and fauna (Field 1996). Still today the majority of rehabilitation programs focus mainly on structural aspects of afforestation (Ellison 2000) thus neglecting to study important issues such as the recolonization of associated fauna which is essential if the multitude of ecological functions of a replanted mangrove forest are to be restored. This is unfortunate as most local artisanal fishing communities do not have access to technology and capital to fish the deeper waters off shore and, as such, are dependent on viable stocks of fish and crustaceans within the mangrove waterways and near-shore waters. But mangroves provide more than just fish and timber products (Ewel *et al.* 1998), and based on this, which ecosystem functions should receive primary focus in restoration? Equally importantly is the question of who should be involved in defining this focus and the ecosystem goods and services provided as a consequence of restoration? If equity issues are to be addressed then the valuation of such goods and services by local users should be taken into consideration. Against this background, this thesis begins by assessing the return of one ecosystem function, the role of mangroves as nursery grounds for juvenile shrimp, based on the scientific notion that this is a valuable ecosystem service provided by mangroves at both local and regional scales (***Paper I***). This is followed by a study of how local user groups perceive and value a range of ecosystem goods and services provided by replanted and natural mangroves (***Paper II***).

Goods and services of mangroves and seascapes – who defines them?

As touch upon above, a number of studies have looked at the ecosystem goods and services provided by mangroves and some have also valued them based on different methods (e.g. Barbier 1994; Ruitenbeek 1994; Bandaranayake 1998; Ewel *et al.* 1998; Janssen & Padilla 1999; Rönnbäck 1999; Lal 2003). This thesis investigates the return of such goods and services in replanted mangroves from a scientific perspective by looking at juvenile shrimp recolonization patterns (***Paper I***) and from the perspectives of local resource users through valuation of ecosystem goods and services (***Paper II***).

While ***Paper II*** deals with a range of ecological goods and services provided by planted and natural mangroves, ***Paper I*** focuses on one ecosystem function identified as important in the literature; the use of replanted fringing forests by juvenile shrimp, with focus on commercially important penaeid species. Results show slightly higher abundances of the majority of shrimp species/taxa caught in the integrated and natural stands of *Sonneratia alba* studied, as compared to the matrix plantation and an adjacent denuded area and there were significant differences in overall shrimp abundance between forested and unvegetated sites. Furthermore, although there were no noticeable differences in species diversity between areas the integrated and natural stands had a more even distribution of species in terms of percentage composition of catch. They also harbored a higher diversity of penaeid species likely due to greater heterogeneity in terms of structural complexity as well as longer inundation time. Although differences between natural and replanted sites were evident, the study tentatively suggests that the habitat function of mangroves as shrimp nurseries is, to some degree, restored in the studied sites. There may be differences in shrimp densities depending on plantation characteristics but results of ***Paper I*** indicate that in order to detect differences in microhabitat preferences for shrimps and evaluating replanted habitat use (as an ecosystem function) in the field may call for an even larger number of samples or investigations focusing on larger spatial scales than in this study. However, increasing the spatial scale of investigation often results in variations in physical factors confounding the sampling design. Hence, ideally, future mangrove planting projects should take such aspects into account in order to increase the possibilities of evaluating the return of related ecological functions.

Ecosystem goods and services have been categorized based on the types of functions they provide. These include *Regulating functions*, concerned with the maintenance of essential ecological processes and life support systems, *Habitat functions*, providing habitat for wild plants and animals, *Production functions*, providing natural resources, and *Information functions*, providing opportunities for cognitive development, i.e. new knowledge about the functioning of the ecosystem (de Groot *et al.* 2002). ***Paper II*** looks at how local resource users perceive the return of ecosystem goods and services in replanted forests when compared to natural and degraded mangroves and bases the analysis on these categories. Results show the majority of identified goods and services to be of significant value to locals but over 60% of interviewed resource users did not feel the plantations could provide these at the time of the study. Although many goods and services were identified by all respondents, discrepancies in their perceived importance were evident between user groups (i.e. fishermen, polecutters, women gleaners etc). For example, fishermen perceived and valued a wider range of resources also related to other parts of the seascape, while polecutters had a narrower focus on tree related products such as timber, and women identified mainly products which by tradition and cultural convention are only harvested by females, like mollusks, fodder and bark for dye production.

Although not studied in depth in ***Paper II*** the level of understanding of ecological processes related to the production of identified goods and services, exemplified above, was correlated with the range in number, and valuation of resources identified by user groups. This pattern is, however, further supported by patterns of local ecological knowledge among user groups in ***Paper III***, discussed below. Discrepancies in the perception and valuation of mangrove associated resources between villages were also evident and these were attributed to factors such as the location of the village vis-à-vis the mangrove ecosystem and inundation zone which affects the composition of the mangrove tree community, in turn affecting the range of goods and services perceived by villagers. Prevalence of fishermen in one village and polecutters and farmers in the other, i.e. a reflection of differences in primary livelihoods, was concluded to be another contributing factor. This partly supports the idea that consumers exhibit preferences at different scales as suggested by (Sagoff 1981). Commodities are thus proposed to be valued by individuals depending on the social context in which decisions are made, be it core family, as resource extractors, as scientists, or as local government representatives (Pritchard Jr. *et al.* 2000). The importance of recognizing the role of social context in defining preferences in management decisions is noted by Pritchard Jr. *et al.* (2000), as environmental valuation based purely on cost-benefit ideology too often runs the risk of mistakenly being viewed as objective. In the case of replanted mangroves and associated goods and services (***Paper II***), the perceived values they provide differ as a result of varying ecological knowledge among groups, differing access to and perceived benefits from the mangroves, and differing social context affecting the view and role played by mangroves among respondents. It is therefore argued that plans to attain sustainable co-management of the mangroves and associated fisheries in the study region in the future will benefit from increased awareness of these discrepancies to avoid conflicting views over the goals of restoration, thereby increasing the feeling of commitment to and ownership over the resource management process.

Linking humans and ecosystems – local ecological knowledge as a prerequisite for understanding and managing resource dynamics

There is no single, universally accepted way of formulating the linkage between social and ecological systems (Berkes & Folke 1998). Factors proposed as governing the relationship humans have with their natural life-support systems will differ depending on discipline, but two such links are exemplified by local ecological knowledge (LEK) and institutions for natural resource management (formal and informal), both of which are dealt with in this thesis (***Papers II, III, IV, VI***). I have chosen to use North's (1990) broad definition of institutions (for a review of institutions as related to fisheries see Jentoft 2004) and define LEK according to Olsson & Folke (2001), as knowledge held by a specific group of people about their local ecosystems. This knowledge may be a mix of scientific and practical knowledge, it is site-specific and often involves a belief component. Consequently LEK differs from traditional ecological knowledge (TEK) in that it often lacks the dimension of historical and cultural continuity. Such is the case in this thesis where traditional belief systems have gradually been replaced by Islam and local communities have experienced a large influx of immigrants in recent decades (***Paper III***, Glaesel 2000).

In trying to find governance structures that adequately deal with natural resource management adaptive co-management is often suggested as a potential solution (Gadgil *et al.* 2000; Brown 2003). Its inclusive nature addresses equity issues by incorporating local stakeholders into the decision-making process. The dynamic, 'life-long' learning, characteristic of adaptive management, is thought to be enhanced through collaboration and combination of different knowledge systems (McLain & Lee 1996; Johannes 1998; Gadgil *et al.* 2003) where LEK held by local user groups constitutes one important component. Implicit in this view is an assumption about the capacity of LEK to be translated practically and fundamentally into alternative approaches for how to manage natural resources (Davis & Wagner 2003).

Yet, as Davis & Wagner (2003) point out, LEK may range from the essential knowledge critical to harvesting a resource successfully, through complex understandings of ecological processes and links at varying spatial and temporal scales, to cultural belief systems characterizing human-environment interactions as "sacred" (Berkes 1999). du Toit *et al.* (2004) follow this lead and argue that in spite of LEK being a vital store of information local practices are often not adapted to the scales and kinds of disturbances generated by contemporary society. It thus appears that for LEK to ever become a cornerstone in natural resource management and play a role in empowering local communities, LEK research must be conducted in such a way that results will accurately reflect the breadth, depth and comparability of these knowledge systems across regions and environmental contexts. This thesis attempts to address this issue by systematically comparing the local ecological knowledge of user groups within the same social-ecological system (***Paper III***). Knowledge is compared among groups of fishermen and to that of non-fishing groups. Furthermore knowledge is analyzed with respect to the scales of ecological processes and disturbances affecting the ecosystem. Mismatches of scale between local knowledge and ecological processes are identified, as well as points of convergence upon which emerging scientific and local community information exchange can build and develop.

Knowledge acquisition and links to resource extraction

Communities are rarely just one single group of local stakeholders, rather they are defined by complicated patterns of subgroups with different perceptions, interests, resources and amount of influence (Carlsson & Berkes 2005; Nygren 2005). The heterogeneity most often also

extends to the patterns of resource use within communities, with different groups focusing their extraction efforts in different parts of the natural system or on different types of resources. Such differentiation in local efforts could be assumed to have an effect on the type and amount of ecological knowledge obtained by different user groups. Yet studies that systematically investigate heterogeneity in knowledge related to extraction are still sparse (Neis *et al.* 1999; Ghimire *et al.* 2004). ***Paper III*** systematically compared the LEK of user groups within a coastal Kenyan community and found significant differences in the level and content of ecological knowledge among occupational categories with respect to the scale and nature of ecological interactions in the seascape. Non-fishing related groups were marked by consistently low levels of knowledge and understanding of all seascape components and processes. Gear defined fisher groups appeared to be linked, through fishing methods, to specific functional groups of marine organisms defined by trophic level, although acknowledgment among users of trophic links and ecosystem effects were not always apparent. ***Papers III*** and ***IV*** argue that such differences in knowledge are related to respondents' primary source of income dictating how much time and effort will be put into learning about the functioning of the natural resource base, but also where in the seascape the primary fishing effort is conducted, as this will define the content of the observations made and upon which knowledge is built. ***Paper IV*** also relates heterogeneous knowledge distribution to social network structure as discussed in the next section.

Analysis (***Paper III*** and ***IV***) also reveals a body of knowledge common to all groups which included acknowledgement of the central role played by mangroves for coastal protection, water quality and as nursery habitat as well as the seasonal rains and related freshwater pulse affecting shrimp migrations. Hunn *et al.* (2003) describe a similar pattern of shared knowledge and simultaneous differences in perceptions of ecological processes and impacts of human egg harvest on gull populations among the Huna Tlingit and note that these differences demonstrate '…*that a culture is a dynamic system of sometimes competing beliefs and practices but a system characterized by certain widely shared understandings*'. This may be so, but the content and scope of the shared knowledge then becomes crucial, as common understanding of system function is judged to be an important prerequisite for successful common pool resource (CPR) management (Ostrom 1990). Provided patterns of heterogeneous LEK are common in other rural settings it thus becomes pertinent to ask what the implications of this can be for the build-up of a common pool of knowledge regarding a shared natural resource and its management? These issues will be dealt with further in the next section.

The problem of scale, non-stationary resources, and complementary aspects of different knowledge systems

In any system, good understanding of system function and ability to respond to changes is essential for effective management. In the case of social-ecological systems (SES) the same holds true, but uncertainty and unpredictability is often so high that instead of aiming to understand every detail of the system one must focus on enhancing adaptive capacity. Adaptive capacity is an aspect of resilience that reflects learning, flexibility to experiment and adopt novel solutions, and development of generalized responses to broad classes of challenges (Walker *et al.* 2002). When aiming for flexible, participatory management approaches, such as adaptive co-management, it becomes crucial that all stakeholders involved share the same, or at least similar, conceptual models of how the system works, its essential components and boundaries. Only then can mutual views on the values of the system and the stakes involved in loosing them evolve.

Knowledge and understanding of ecosystem dynamics is often complex and difficult to develop at the level of a single individual (Olsson 2004). As discussed above, in many settings the bulk of individual knowledge is acquired from observations in the area of primary

extraction effort (***Paper III***). To attain a more holistic view, collaboration is needed and through communication between holders of different knowledge a deeper understanding of system function and responses to change can develop (***Paper IV***, McIntosh 2000). One reason why building a comprehensive understanding of a SES is difficult at the individual level is the physical limit in geographical range that a single individual can span during his/her resource extraction, e.g. fishing operations. Another one relates to the way memory is built up and accumulated into 'knowledge'. For example, seeing things that are potentially important for one's livelihood and its future will be remembered with greater clarity and detail than observation of things thought to be of less importance (Davis *et al.* 2004). This phenomenon is well studied in social psychology and is referred to as the 'availability heuristic' (Tversky & Kahneman 1973). Both of these factors will affect the spatial and temporal scales at which awareness among local stakeholders of ecological processes and potential disturbances occurs. Other factors relate to the nature of the resource itself. For example, it is more difficult to acquire a comprehensive understanding of stock size and dynamics of highly mobile resources like pelagic fish stocks than for stationary resources with high storage potential like forests (Agrawal 2002). Yet the spatial distribution of stationary resources will also affect knowledge acquisition as described in ***Paper II***, where perceptions of ecological goods and services (naturally linked to ecological functions) are affected by the distance of the mangrove plantations and the rest of the seascape components to the village. However, these problems of scale linked to gaps in knowledge acquisition of both local users and scientists have the potential of being greatly reduced through combination of the various knowledge systems (***Paper III***, Olsson & Folke 2001; Becker & Ghimire 2003; Aswani & Hamilton 2004; Moller *et al.* 2004). Both science and LEK suffer from the difficulty in capturing cross-scale linkages, but combinations of the two may reduce uncertainties. While LEK is often poor in detecting shifts in average patterns of ecological parameters, science is likely to miss occasional extreme events (captured by daily local observations) due to short sampling duration (Moller *et al.* 2004). In ***Paper III*** the recognition by fishermen of extreme climatic events such as El Niño and its effect on reefs, shrimp populations, mangroves and seagrass coverage, is one example. Their poor recognition of declining fish stocks, differing scales of fish migrations and lack of insight into causal relationships affecting the status of the seagrass meadows are also good examples of the potential for complementarities in combining science and LEK in this community.

Features put forth as essential for building resilience in social-ecological systems, through adaptive co-management, include ability for monitoring and responding to environmental feedbacks and combining various sources of information for ecosystem management (Olsson 2004). Both of these issues are treated in ***Paper III*** and have been discussed above. Other features proposed as important are information flow and social networks (Tompkins & Adger 2004) as well as sense-making and leadership for ecosystem management (Olsson 2004). Social networks constitute the fabric of social life and are the means by which much information and knowledge is transferred. Furthermore, knowledge is dynamic and dependent on social networks of communication to perpetuate, build up and be maintained. Through social ties among individuals, structures are formed that in different ways affect the role and power of individuals in a network. In effect, social networks are the vehicles by which leaders and sense-makers are able to capitalize on their network position to disseminate information, spread opinions, and seek support for and instigate collective action. Studying the role of networks in adaptive co-management and their relation to social-ecological resilience is therefore essential and will be dealt with in the next section.

Social networks and their role in natural resource management

This section of the thesis attempts to empirically study some aspects of social networks and their potential link to resilience of social-ecological systems. It does so by continuing to use the case community to look at the role of social networks in knowledge distribution (***Paper IV***) as well as exploring how they can be used to identify influential individuals (also termed key individuals) (***Paper V***). ***Paper V*** also uses social network analysis to assess social capital and relates the position and characteristics of key individuals to agency and collective action for natural resource management. Agency, in this respect, is seen as the action of mobilizing the stock of social capital of the community. Furthermore the social capital explored in ***Paper V*** is argued to facilitate and enhance the role played by middlemen in coastal, rural SES, as described in ***Paper VI***.

In literature on common pool resource management (CPR) and environmental conservation, conditions often cited as important for success include facilitation of information flow; combination of various sources of information and knowledge systems for increased understanding of system function; high levels of social capital inducing trust, reciprocity and the potential for effective monitoring of rule compliance (e.g. Ostrom 1990; Pretty & Ward 2001; Dietz *et al.* 2003; Pretty 2003; Olsson 2004; Tompkins & Adger 2004). All of these conditions are, to some degree, dependent on social networks. Social relations are the means by which much information and knowledge is transferred, frequency of interaction builds trust (Alesina & La Ferrara 2002; Okten & Osili 2004) and trust lubricates cooperation to reduce transaction costs between people (Pretty & Ward 2001). But coordination of initiatives for collective action related to resource management is also argued to rely on individuals taking the role of leaders to instigate action, synthesize information and link communities to higher levels of institutional hierarchy (Westley & Vredenburg 1997; Krishna 2002; Folke *et al.* 2003; Olsson 2004). In the field of sociology and social network analysis, networks are not seen as something inherently good but as structures that offer both possibilities and constraints for action and agency (Degenne & Forsé 1999). ***Papers IV*** and ***V*** of this thesis study networks of information and knowledge exchange to look at the relation between social network structure and distribution of LEK. ***Paper V*** also uses network measures to identify key individuals and discuss their potential role in instigating collective action with respect to natural resource management. Both of these studies show that potentially both positive and negative aspects can be discerned from network structure with respect to resource management and adaptive capacity.

Communication among stakeholders and distribution of knowledge

Adaptive co-management is a type of governance approach designed to involve local stakeholders to a large extent, promoting ownership over issues and creating incentives for collective management (Gadgil *et al.* 2000; Brown 2003). Yet, to be successful it requires common understanding of ecosystem function (Ostrom 1990, 2005) which, in turn, requires sharing of information and networks of communication for knowledge transfer. ***Papers III*** and ***IV*** found heterogeneous distribution of LEK among resource users and non-extracting occupational groups, which correlates with the structure of the social network of communication regarding resource-related information. ***Paper IV*** also shows that gear-defined occupation plays an important role in defining resource-related communication structures indicating that fishermen are, in fact, not a homogenous stakeholder group but consist of a number of subgroups, communicating primarily with members of their own occupational category. At the same time weak ties of local businessmen to coastal resource extractors likely explains their lack of ecological knowledge (in addition to the fact that they

are not directly involved in resources extraction). It as argued, in this context, that the social homogeneity within subgroups exhibited in the social network studied, enhances tacit knowledge transfer (Cross 2001), i.e. transfer of knowledge regarding complex ecological processes.

Paper IV demonstrates that structures in relational networks are important for identifying central and potentially influential actors and indicates that incentives and attributes that enable these actors to emerge as leaders and coordinate and instigate collective action are essential for successful co-management. Without the appropriate incentives and knowledge, favorably positioned actors will not exploit their positions to initiate collective action. In this study, this was exemplified by the centrally positioned group of deep sea fishermen who have not taken any initiatives to regulate resource extractions. As such they may, in fact, act as barrier for collective action since highly motivated, but less central actors have difficulty initiating action due to less favorable positions. Furthermore, potentially influential actors, here represented by local businessmen, are loosely tied to the communication network of resource extractors. Thus, their lack of knowledge and access to information on resource status is likely to negatively affect their incentive to engage in collective action initiatives even though they could play an instrumental role through their ties to village committees and other institutional hierarchies. Such ties have been seen to enhance the capacity of local communities to mobilize for collective action (Berkes in press) but are often an attribute of a select number of individuals in a community. These individuals can thus become key players, in a sense, but their personal attributes can be seen to have an effect on their potential to amass support for joint community ventures (Krishna 2002). Agency, in this respect, is related to the social capital of the leaders but also to the stock of social capital in the community as a whole (Krishna 2002).

Social capital, leadership and agency – what effect on natural resource management?

The concept of social capital offers a way to bridge sociological and economic perspectives to provide potentially better explanations for economic development (Woolcock & Narayan 2000), but also for performance of sustainable natural resource management (Pretty & Smith 2004). Social capital has been defined in several different, and sometimes contradictory, ways (see e.g. Lin 1999; Woolcock & Narayan 2000; Krishna 2002 for review). First, the unit of analysis can vary from the individual to the group (Borgatti *et al.* 1998; Portes 1998). For example, Burt (2004) argues that linkages to different groups may enhance an individual's social capital, whereas Putnam (1993) discusses social capital at the scale of whole nations.

Secondly, there is a lack of agreement of what actually constitutes social capital. For example, Putnam (1993) defines social capital as "features of social organization such as networks, norms and social trust that facilitate coordination and cooperation for mutual benefit". Social network scientists, on the other hand, define social capital as "resources embedded in a social structure which are accessed and/or mobilized in purposive actions" (Lin 1999), thus leaving out collective assets such as trust and norms (even though most acknowledge that e.g. trust may promote social relations and vice versa).

Finally, several theses exist differing primarily in their view of social capital as either an exogenous or an endogenous variable with effects on the conclusions drawn and the explanatory capacity of social capital. This thesis follows the intermediate position taken by Berman (1997), Krishna (2002), and Dale and Onyx (2005), among others, who argue that social capital has some explanatory potential but that other factors also contribute to

institutional performance and collective action. One such factor is agency which is realized through the existence of agents, i.e. influential individuals, to activate a potentially latent stock of social capital and use it to produce a flow of benefits.

Paper V identifies a set of potential key individuals with the help of network metrics, attempts to assess community social capital, and describes and assesses attributes of these key individuals in relation to their potential to instigate collective action. The study was undertaken as the community has not been successful in regulating the inshore local fishery which has led to a system currently diagnosed as overexploited (McClanahan *et al.* 1997; Ochiewo 2004). Consequently the paper seeks to explore possible explanations for this by addressing aspects of social capital. Results show that levels of community social capital can differ depending on which aspect is in focus. While network measures can indicate relatively high levels of social capital, reluctance to report rule-breaking could actually be reinforced by cohesive social networks and potentially counter-balance the former. The study also identified key individuals and showed them to possess links to a number of external agencies although links to financial institutions and markets beyond the trade of fishing-gear were in minority. The ratio between bonding and bridging ties in the community knowledge network appeared balanced. Bonding ties accounted for over 50% of reported relations in all but one group, yet never more than 75%. Our findings thus suggest that levels of social capital cannot entirely account for lack of collective action. Instead we propose that attributes of influential individuals may also significantly affect agency. Poor problem internalization (i.e. recognition of overexploitation as a potential threat to future livelihoods) and recognition of changing ecological conditions among these individuals, combined with marked homogeneity in this group in terms of occupation - with effects on their collective ability to perceive and synthesize new information and knowledge - are likely to have contributed to the current situation. Fifty percent of identified key individuals were deep sea fishermen. As ***Paper IV*** shows, this group does not perceive an immediate problem of over-fishing as their operations are more mobile than groups using other gears. We therefore argue that lack of problem internalization may occur in spite of high levels of ecological knowledge within a group if personal identification with an area, or sense of place (Jorgensen & Stedman 2001), is not prevalent. Furthermore, the homogeneity of identified key individuals may reduce the community's ability to adapt to new circumstances, decreasing adaptive capacity.

Structural characteristics of the networks among key individuals reveal one individual to occupy not only a very central position, but also to possess the only link to the formally appointed government official. This may be beneficial for coordination of collective action initiatives but may also impose barriers for initiatives if communal interests conflict with personal agendas. The adaptive capacity of the community in this context is thus largely related to the characteristics and behaviour of one very central actor.

Linking the social and ecological components of SES

The concept of linked social-ecological systems (SES) emerged in an effort to make linkages between the human and ecological components more explicit, as well as focusing on feedback mechanisms by which the two are coupled (Berkes & Folke 1998; Folke *et al.* 2005). Identifying these links enables us to track the feedbacks between social and ecological systems and is essential for sustainable adaptive resource management. Much research effort has focused on how to manage the ecological component while also devising policy instruments to influence resource extractors. While institutions for the management of natural resources are studied extensively, understanding the links between the two systems for improved ecosystem management and governance is a rapidly developing but largely unexplored area,

within the discourse of conservation, natural resource management and linked SES. To date, links and feedback mechanisms have been addressed from the perspectives of local ecological knowledge among resource users and its effect on resource related institutions and management decisions (Berkes 1999; Olsson & Folke 2001; Aswani & Hamilton 2004); patterns of remittances affecting livelihood diversification and resource exploitation (Adger *et al.* 2002; Curran 2002; Gammage *et al.* 2002; Naylor *et al.* 2002); property rights affecting conservation incentives and resource management (Acheson 1988; Ostrom 1990), to name a few.

Paper VI of the thesis proposes another such link between the two systems; to our knowledge previously not investigated within the context of natural resource management and linked SESs. This link is represented by middlemen involved in small-scale fisheries. By middlemen we refer to the group of fish mongers involved in direct contact with fishermen at the landing sites often commissioned as agents for larger collectors (c.f. Gibbon 1997). We argue that they constitute a critical link between the social and ecological system in small-scale fisheries in East Africa, and potentially in developing countries world wide, by directly linking resource extractors and local markets and through their role as informal micro-financing institutions buffering seasonal fluctuations in income related to fishing patterns. Despite their central role within a SES context they have, so far, not been embraced by any governance structure nor formally recognized by policy for resource management, to any large extent.

While ***Paper V*** looked at social capital from a network perspective in an attempt to operationalize measurements of this asset, ***Paper VI*** rests on a more general definition of the concept as the norms and networks that enable people to act collectively (Woolcock & Narayan 2000). This broader definition focuses on the sources, rather than the consequences of social capital (Portes 1998), while recognizing that trust and reciprocity is developed in an iterative process. The existence of social capital, in this form, is what facilitates and enhances the role played by middlemen in coastal, rural SES, described in ***Paper VI***. It allows for the existing credit system, whereby middlemen tie fishermen to operations to secure income and generate business, creating a strong two-way dependency. This in turn has effects on resource extraction and dynamics. Based on the current role of middlemen in East Africa, three different trajectories for the development of small-scale coastal fisheries are outlined and their implications for management discussed. In short, the role of middlemen in social-ecological resilience emerges as crucial and middlemen, as a group, are put forth as a potentially important group to target for future effective management at the local scale.

Concluding remarks

The Millennium Ecosystem Assessment appraisal of the health of the world's ecosystems reveals alarming environmental degradation caused by human activity but also instills some hope by showing that, through good governance, we can better manage our natural resources and, by doing so, secure their benefits for the future (MA 2005).

Natural resource management may entail both preventive and reactive measures. One example of a reactive measure is to restore degraded habitats. This thesis has studied one such rehabilitation initiative, replanted mangroves, with focus on the return of the associated ecosystem function as nursery habitat for juvenile shrimp assemblages (***Paper I***). It is apparent that replanted mangroves do harbor significant numbers of juvenile shrimp compared to unvegetated, degraded areas, although species assemblages differ between replanted and natural sites. In addition to ecological examination, the thesis also investigates how local resource users perceive the return of ecosystem goods and services in these replanted forests (***Paper II***). Results suggest that valuation of these goods and services is related to a number of factors, such as degree of dependence on the resource, and type of resource extraction or occupation, both of which in turn are linked to acquisition of specific ecological knowledge about the resource. Such patterns of distinct local ecological knowledge (LEK) among resource user groups are reinforced in ***Paper III*** and it is concluded that they are in part due to the extractive nature of the LEK exhibited.

Policy debates on CPR management are often flawed because they ignore the fact that the assumptions, knowledge and understandings that underlie the definition of resource problems are frequently uncertain and contested (Adams *et al.* 2003). Intercommunity differences in perceptions of natural resources can lead to cognitive conflicts, and failure to recognize the cognitive dimension of conflict in policy making results in superficial policy measures that fail to address the deeper underlying differences between resource users (Adams *et al.* 2003). Identifying differences in perceptions is thus critical. It may not always guarantee win-win situations but will smooth the way for consensus-building. This thesis provides empirical data on differences and similarities in local ecological knowledge and perceptions held by user groups in a case community (***Paper III***) and links these to the social network for communication of resource related information and knowledge (***Paper IV***). Although proof of causality is an inherent problem in studying social networks the thesis nonetheless suggests that the structure of social networks does play an important role in resource management by affecting the motivation among inhabitants to engage in collective action (***Paper IV***) as well as the ability of centrally positioned actors to access social capital and initiate such action (***Paper V***). Thus the thesis adds to the growing body of data indicating that groups of actors in a network can both help and hinder development, as noted by Woolcock and Narayan (2000). By mapping both the social network for resource related communication and gaps in LEK exhibited, it also identifies areas where science and LEK can meet and trust between local stakeholders and scientists be built upon by mutual learning and exchange of information to enhance resource management and consensus. This will promote ownership into the management process and assessment of resource status among stakeholders (Neis *et al.* 1999).
Finally, this thesis set out to increase our understanding of the links between the social and ecological systems operating in a coastal community. One such link, LEK, is treated in ***Papers III*** and ***IV***. Another is identified in ***Paper VI***, namely middlemen, which are shown to function as a critical group through which feedbacks between the social and ecological system are channeled. This paper also provides empirical support to the notion that institutions, such as the informal type exemplified by middlemen, which has evolved over time, are not necessarily designed to be socially efficient (North 1990).

Combined, the papers that make up this thesis shed new light on some aspects of natural resource management which relate to the nature of LEK, transfer of such knowledge among user groups through social networks, and how social capital captured in social relations can create both possibilities and barriers to sustainable resource management.

Looking ahead…

This thesis has taken a case study approach. This has allowed for a high resolution and in-depth analysis of the aspects in focus. It does, however, reduce the possibility for generalizations. To build on the empirical base collected during this work and thereby expand the applicability and increase the robustness of conclusions which can be drawn, it is my hope that further, similar studies of small-scale communities involved in direct resource extraction can be initiated. Additional research on how the structure of social networks may affect natural resource management is needed and further development and empirical studies of the nature and effect of social capital would be desirable. Furthermore, difficulty in proving causality between social network structure and dependent variables makes longitudinal studies, or a large empirical base of cases, necessary to be able to generate more general theories on how these structures are related to successful resource management.

The mangrove ecosystem in focus at the beginning of this thesis is a complex and heterogeneous system which makes it challenging for accurate replication in ecological research, particularly in rehabilitated areas which are often of limited size. Nonetheless, research into the return of associated, non-forest functions in these replanted areas needs to be continued and expanded to increase our knowledge of the time and spatial scales involved in attaining well functioning ecosystems, providing the same, or at least a similar, range of goods and services as pristine habitats. It is my hope that these issues will be taken into account in future replanting programs and initiatives.

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References

Abuodha, P.A. & Kairo, J.G. (2001) Human-induced stress on mangrove swamps along the Kenyan coast. *Hydrobiologia* **458**: 255-265.

Acheson, J. (1988) *The Lobster Gangs of Maine*. Hanover: University Press of New England.

Adams, W.M., Brockington, D., Dyson, J. & Vira, B. (2003) Managing Tragedies: Understanding Conflict over Common Pool Resources. *Science* **302**: 1915-1916.

Adger, N., Kelly, M., Winkels, A., Quang Huy, L. & Locke, C. (2002) Migration, remittances, livelihood trajectories, and social resilience. *Ambio* **31**: 358-365.

Adger, W.N. (2000) Social and ecological resilience: are they related? *Human Geography* **24**: 347-364.

Agrawal, A. (2002) Common resources and institutional sustainability. In: *The Drama of the Commons,* eds. Ostrom, E., Dietz, T., Dolsak, N., Stern, C., Stovich, S. & Weber, E. Washington, DC: National Academy Press.

Alesina, A. & La Ferrara, E. (2002) Who trusts others? *Journal of Public Economics* **85**: 207-234.

Alidina, H. (2005) Local level fisheries management in Diani-Chale, Kenya: Current status and future directions. *Coastal Management* **33**: 459-470.

Alongi, D.M. (2002) Present state and future of the world's mangrove forests. *Environmental Conservation* **29**: 331-349.

Aswani, S. & Hamilton, R.J. (2004) Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental Conservation* **31**: 69-83.

Bandaranayake, W.M. (1998) Traditional and medicinal uses of mangroves. *Mangroves and Salt Marshes* **2**: 133-148.

Baran, E. & Hambrey, J. (1998) Mangrove conservation and coastal management in Southeast Asia: What impact on fishery resources? *Marine Pollution Bulletin* **37**: 431-440.

Barbier, E.B. (1994) Valuing environmental functions: Tropical wetlands. *Land Economics* **70**: 155-173.

Becker, C.D. & Ghimire, K. (2003) Synergy between traditional ecological knowledge and conservation science supports forest preservation in Ecuador. *Conservation Ecology* **8**

Benthem, W., van Lavieren, L.P. & Verheugt, W.J.M. (1999) Mangrove rehabilitation in the coastal Mekong delta, Vietnam. In: *An international perspective on wetland rehabilitation,* ed. Streever, W., pp. 29-36. Netherlands: Kluwer Academic Publishing.

Berkes, F. (1999) *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*. Philadelphia: Taylor & Francis.

Berkes, F. (in press) From community-based resource management to complex systems: the scale issue and marine commons. *Ecology and Society*

Berkes, F. & Folke, C. (1998) *Linking Social and Ecological Systems*. Cambridge: Cambridge University Press.

Berman, S. (1997) Civil society and the collapse of the Weimar Republic. *World Politics* **49**: 401-429.

Borgatti, S.P., Jones, C. & Everett, M. (1998) Network measures of social capital. *Connections (INSNA)* **21**: -36.

Brown, K. (2003) Integrating conservation and development: a case of institutional misfit. *Frontiers In Ecology and the Environment* **1**: 479-487.

Burt, R. (2004) Structural Holes and Good Ideas. *American Journal of Sociology* **110**: 349-399.

Burt, R.S. & Minor, M.J. (1983) *Applied Network Analysis: A Methodological Introduction*. Beverly Hills: Sage.

Carlsson, L. (2000) Policy networks as collective action. *Policy Studies Journal* **28**: 502-520.

Carlsson, L. & Berkes, F. (2005) Co-management: concepts and methodological implications. *Journal of Environmental Management* **75**: 65-76.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & van der Belt, M. (1997) The value of the world's ecosystem services and natural capital. *Nature* **387**: 253-260.

Cross, R., Borgatti, S. P. and Parker, A. (2001) Beyond answers: Dimensions of the advice network. *Social Networks* **23**: 215-235.

Curran, S.R. (2002) Migration, social capital and the environment: considering migrant selectivity and networks in relation to coastal ecosystems. *Population and Development Review* **28**: 89-125.

Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G. & Koedam, N. (2000) Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Economic Botany* **54**: 513-527.

Dale, A. & Onyx, J. (2005) *A dynamic balance: social capital and sustainable community development*. Vancouver, BC, Canada.

Davis, A., Hanson, J.M., Watts, H. & MacPherson, H. (2004) Local ecological knowledge and marine fisheries research: the case of white hake (Urophycis tenuis) predation on juvenile American lobster (Homarus americanus). *Canadian Journal of Fisheries and Aquatic Science* **61**: 1191-1201.

Davis, A. & Wagner, J.R. (2003) *Who* knows? On the importance of identifying 'experts' when researching local ecological knowledge. *Human Ecology* **31**: 463-489.

de Groot, R.S., Wilson, M.A. & Boumans, R.M.J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* **41**: 393-408.

Degenne, A. & Forsé, M. (1999) *Introducing Social Networks*. London: Sage Publications.

Dietz, T., Ostrom, E. & Stern, P.C. (2003) The struggle to govern the commons. *Science* **302**: 1907-1912.

du Toit, J.T., Walker, B. & Campbell, B.M. (2004) Conserving tropical nature: current challenges for ecologists. *Trends in Ecology & Evolution* **19**: 12-17.

Ellison, A.M. (2000) Mangrove Restoration: Do we know enough? *Restoration Ecology* **8**: 219-229.

Ewel, K.C., Twilley, R.R. & Ong, J.E. (1998) Different kinds of mangroves provide different goods and services. *Global Ecology and Biogeography Letters* **7**: 83-94.

FAO (2000). Indonesia Fishery Profile. Food and Agriculture Organization of the United Nations, Rome, Italy.

Field, C.D. (1996) *Restoration of mangrove ecosystems*. Okinawa, Japan: International Society for Mangrove Ecosystems.

Folke, C. (2006) Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* **XX**: xx-xx.

Folke, C., Colding, J. & Berkes, F. (2003) Synthesis: Building resilience and adaptive capacity in social-ecological systems. In: *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change,* eds. Berkes, F., Folke, C. & Colding, J., pp. 352-387. Cambridge: Cambridge University Press.

Folke, C., Hahn, T., Olsson, P. & Norberg, J. (2005) Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources* **30**: 441-473.

Freeman, L. (1979) Centrality in social networks. Conceptual clarifications. *Social Networks* **1**: 215-239.

Gadgil, M., Olsson, P., Berkes, F. & Folke, C. (2003) Exploring the role of local ecological knowledge in ecosystem management: three case studies. In: *Navigating Social-Ecological*

Systems: Building Resilience for Complexity and Change, eds. Berkes, F., Colding, J. & Folke, C., pp. 189-209. Cambridge: Cambridge University Press.
Gadgil, M., Rao, P.R.S., Utkarsh, G., Pramod, P. & Chhatre, A. (2000) New meanings for old knowledge: The People's Biodiversity Registers program. *Ecological Applications* **10**: 1307-1317.
Gammage, S., Benítez, M. & Machado, M. (2002) Property rights, multiple stakeholders and competing demands: the challenges of mangrove management in El Salvador. *Ambio* **31**: 285-294.
Ghimire, S.K., McKey, D. & Aumeeruddy-Thomas, Y. (2004) Heterogeneity in Ethnoecological knowledge and management of medicinal plants in the Himalayas of Nepal: Implications for conservation. *Ecology and Society* **9**: online.
Gibbon, P. (1997) Prawns and piranhas: the political economy of a Tanzanian private sector marketing chain. *Journal of Peasant Studies* **25**: 1-86.
Glaesel, H. (1997) Fisher, Parks and Power : The socio-environmental dimentions of marine resource decline and protection on the Kenya coast. PhD Thesis. In. University of Wisconsin-Madison
Glaesel, H. (2000) State and local resistance to the exapnsion of two environmentally harmful marine fishing techniques in Kenya. *Society and Natural Resources* **13**: 321-338.
GOK (1991). The fisheries act, chapter 378. Government of Kenya, Nairobi.
GOK (2001). The fisheries act, chapter 378 Susidiary Legislation. Government of Kenya, Nairobi.
Granovetter, M. (1973) The strength of weak ties. *American Journal of Sociology* **76**: 1360-80.
Hogarth, P.J. (1999) *The biology of mangroves*. Oxford, England: Oxford University Press.
Hunn, E.S., Johnson, D.R., Russel, P.N. & Thornton, T.F. (2003) Huna Tinglit traditional environmental knowledge, conservation, and the management of a 'wilderness' park. *Current Anthropology* **44**: S79-S103.
Imbert, D., Rousteau, A. & Scherrer, P. (2000) Ecology of mangrove growth and recovery in Lesser Antilles: State of knowledge and basis for restoration projects. *Restoration Ecology* **8**: 230-236.
Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. & Warner, R.R. (2001) Historical overfishing and recent collapse of coastal ecosystems. *Science* **293**: 629-638.
Jackson, L.L., Lopoukhine, N. & Hillyard, D. (1995) Ecological restoration: a definition and comments. *Restoration Ecology* **3**: 71-75.
Janssen, R. & Padilla, J.E. (1999) Preservation or Conservation? Valation and evaluation of a mangrove forest in the Philippines. *Environmental and Resource Economics* **14**: 297-331.
Jentoft, S. (2004) Institutions in fisheries: what they do, and how they change. *Marine Policy* **28**: 137-149.
Johannes, R.E. (1998) The case for data-less marine resource management: examples from tropical nearshore fisheries. *Trends in Ecology and Evolution* **13**: 243-246.
Jorgensen, B.S. & Stedman, R.C. (2001) Sense of place as an attitude: Lakeshore owners attitudes towards their properties. *Journal of Environmental Psychology* **21**: 233-248.
Krishna, A. (2002) *Active social capital. Tracing the roots of development and democracy*. New York: Columbia University Press.
Kura, Y., Revenga, C., Hoshimo, E. & Mock, G. (2004). *Fishing for answers: Making sense of the global fish crisis.* World Resource Institute, Washington, DC.
Lal, P. (2003) Economic valuation of mangroves and decision-making in the Pacific. *Ocean & Coastal Management* **46**: 823-844.

Lewis, R.R. (1999) Key concepts in successful ecological restoration of mangrove forests. In: *Proceedings from the TCE-Workshop No. II, Coastal Environmental Improvement in Mangrove/Wetland Ecosystems*, pp. 19-32. Bangkok, Thailand: (TCE) Research and Training, NACA.

Lin, N. (1999) Building a network theory of social captial. *Connections* **22**: 28-51.

Lindén, O. & Lundin, C.G. (1996) *Integrated coastal zone management in Tanzania*. Sweden: World Bank, Environmental Department and Sida, Department of Research Cooperation, SAREC.

Millenium Ecosystem Assessment. MA (2005). Ecosystems and human well-being: Biodiversity synthesis. Island Press, Washington, DC.

Matthes, H. & Kapetsky, J.M. (1988). Worldwide Compendium of Mangrove-Associated Aquatic Species of Economic Importance. FAO Fishery Circular No. 814, Rome.

McClanahan, T.R., Glaesel, H., Rubens, J. & Kiambo, R. (1997) The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. *Environmental Conservation* **24**: 105-120.

McIntosh, R.J. (2000) Social memory in Mande. In: *The way the wind blows: Climate, History, and Human Action,* eds. McIntosh, R. J., Tainter, J. A. & McIntosh, S. K., pp. 141-180. New York: Columbia University Press.

McLain, R. & Lee, R. (1996) Adaptive management: promises and pitfalls. *Journal of Environmental Management* **20**: 437-448.

Moller, H., Berkes, F., O'Brian Lyver, P. & Kislalioglu, M. (2004) Combining science and tradtitional ecological knowledge: monitoting populations for co-management. *Ecology and Society* **9**: online.

Morgan, D.L. (1988) *Focus groups as qualitative research*. Beverly hills, CA: Sage Publications Inc.

Naylor, R.L., Bonine, K.M., Ewel, K.C. & Waguk, E. (2002) Migration, markets, and mangrove resource use on Kosrae, Federated States of Micronesia. *Ambio* **31**: 340-350.

Neis, B., Schneider, D., Felt, L., Haedrich, R., Fischer, J. & Hutchings, J. (1999) Fisheries assessment: what can be learned from interviewing resource users? *Canadian Journal of Fisheries and Aquatic Science* **56**: 1949-1963.

Newman, M.E.J. & Girvan, M. (2004) Finding and evaluating community structure in networks. *Physical Review E* **69**: 026113.

North, D.C. (1990) *Institutions, Institutional Change and Economic Performance (Political Economy of Institutions and Decision)*: Cambridge University Press.

Nygren, A. (2005) Community-based forest management within the context of institutional decentralization in Honduras. *World Development* **33**: 639-655.

Ochiewo, J. (2004) Changing fisheries practices and their social implications in south coast Kenya. *Ocean & Coastal Management* **47**: 389-408.

Okten, C. & Osili, U.O. (2004) Social Networks and Credit Access in Indonesia. *World Development* **32**: 1225-1246.

Olsson, P. & Folke, C. (2001) Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken Watershed, Sweden. *Ecosystems* **4**: 85-104.

Olsson, P., Folke, C. and Berkes, F. (2004) Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management* **34**: 75-90.

Ong, J.-E. (1995) The ecology of mangrove conservation and management. *Hydrobiologia* **295**: 343-351.

Ostrom, E. (1990) *Governing the Commons: The Evolution of Institutions for Collective Action*: Cambridge University Press.

Ostrom, E. (2005) *Understanding Institutional Diversity*. Bloomington: Princeton University Press.

Portes, A. (1998) Social capital: Its origins and applications in modern sociology. *Annual Review of Sociology* **22**: 1-24.

Pretty, J. (2003) Social capital and the collective management of resources. *Science* **302**: 1912-1914.
Pretty, J. & Smith, D. (2004) Social capital in biodiversity conservation and management. *Conservation Biology* **18**: 631-638.
Pretty, J. & Ward, H. (2001) Social Capital and the Environment. *World Development* **29**: 209-227.
Primavera, J.H. (2000) Development and conservation of Philippine mangroves: institutional issues. *Ecological Economics* **35**: 91-106.
Primavera, J.H. (2005) Mangroves, fishponds, and the quest for sustainability. *Science* **310**: 57-59.
Pritchard Jr., L., Folke, C. & Gunderson, L.H. (2000) Valuation of ecosystem services in institutional context. *Ecosystems* **3**: 36-40.
Putnam, R.D. (1993) *Making democracy work. Civic traditions in modern Italy*. Princeton, NJ: Princeton University Press.
Redman, C.L. (1999) *Human Impact on Ancient Environments*. Tucson: University of Arizona Press.
Ruitenbeek, H.J. (1994) Modeling economy - ecology linkages in mangroves: economic evidence for promoting conservation in Bintuni Bay, Indonesia. *Ecological Economics* **10**: 229-247.
Rönnbäck, P. (1999) The ecological basis for the economic value of mangrove forests in seafood production. *Ecological Economics* **29**: 235-252.
Rönnbäck, P. (2001). Shrimp aquaculture. State of the art. Report 1, Swedish Centre for Environmental Impact Assessment, SLU, Uppsala.
Rönnbäck, P., Macia, A., Almqvist, G. & Schultz, L. (2001) Do penaeid shrimps have a preference for mangrove habitats? Distribution pattern analysis on Inhaca Island. *Estuarine, Coastal and Shelf Science* **55**: 427-436.
Saenger, P. & Siddiqi, N.A. (1993) Land from the sea: The mangrove afforestation program of Bangladesh. *Ocean & Coastal Management* **20**: 23-39.
Sagoff, M. (1981) At the Shrine of Our Lady Fatima or why political questions are not all economic. *Arizona Law Review* **23**: 1283-98.
Scott, J. (2000) *Social Network Analysis. A handbook*. 2 edn. London: Sage Publications.
Semesi, A.K. (1998) Mangrove management and utilization in Eastern Africa. *Ambio* **27**: 620-626.
Singleton, S. (1998) *Constructing cooperation: the evolution of institutions of comanagement*. Ann Arbor: University of Michigan Press.
Sloan, N.A. & Sugandhy, A. (1994) An overview of Indonesian coastal environmental management. *Coastal Management* **22**: 215-233.
Thayer, G.W., Colby, D.R. & Hettler, J.W.F. (1987) Utilization of the red mangrove prop root habitat by fishes in South Florida. *Marine Ecology Progress Series* **35**: 25-38.
Tompkins, E.L. & Adger, W.N. (2004) Does adaptive management of natural resources enhance resilience to climatic change? *Ecology and Society* **9**: art10.
Tversky, A. & Kahneman, D. (1973) The availability heuristic for judging frequency and probability. *Cognitive Psychology* **5**: 207-232.
Valiela, I., Bowen, J.L. & York, J.K. (2001) Mangrove forests: One of the world's most threatened major tropical environments. *Bioscience* **51**: 807-815.
Walker, B., Carpenter, S., Anderies, J.M., Abel, N., Cumming, G., Janssen, M.A., Lebel, L., Norberg, J., Peterson, G. & Pritchard, R. (2002) Resilience Management in Social-ecological Systems: a Working Hypothesis for a Participatory Approach. *Conservation Ecology* **6**
Vance, D.J., Haywood, M.D.E., Heales, D.S., Kenyon, R.A., Loneragan, N.R. & Pendrey, R.C. (1996) How far do prawns and fish move into mangroves? Distribution of juvenile

banana prawns *Penaeus merguiensis* and fish in a tropical mangrove forest in northern Australia. *Marine Ecology Progress Series* **131**: 115-124.

Wasserman, S. & Faust, K. (1994) *Social Network Analysis - Methods and applications*. Cambridge: Cambride University Press.

Wellman, B. (1988) Structural analysis: From metaphor to theory and substance. In: *In: Social structures: A network approach,* eds. Wellman, B. & Berkowitz, S. D., pp. 19-61. New York: Cambridge University Press.

Westley, F. & Vredenburg, H. (1997) Interorganizational Collaboration and the Preservation of Global Biodiversity. *Organization Science* **8**: 381-403.

Woolcock, M. & Narayan, D. (2000) Social capital: Implications for development theory, research and policy. *The World Bank Research Observer* **15**: 225-249.

WRI (2005). World Resources 2005: The Wealth of the Poor - Managing Ecosystems to Fight Poverty. World Resources Institute in collaboration with UNDP, UNEP and World Bank, Washington, DC:WRI.

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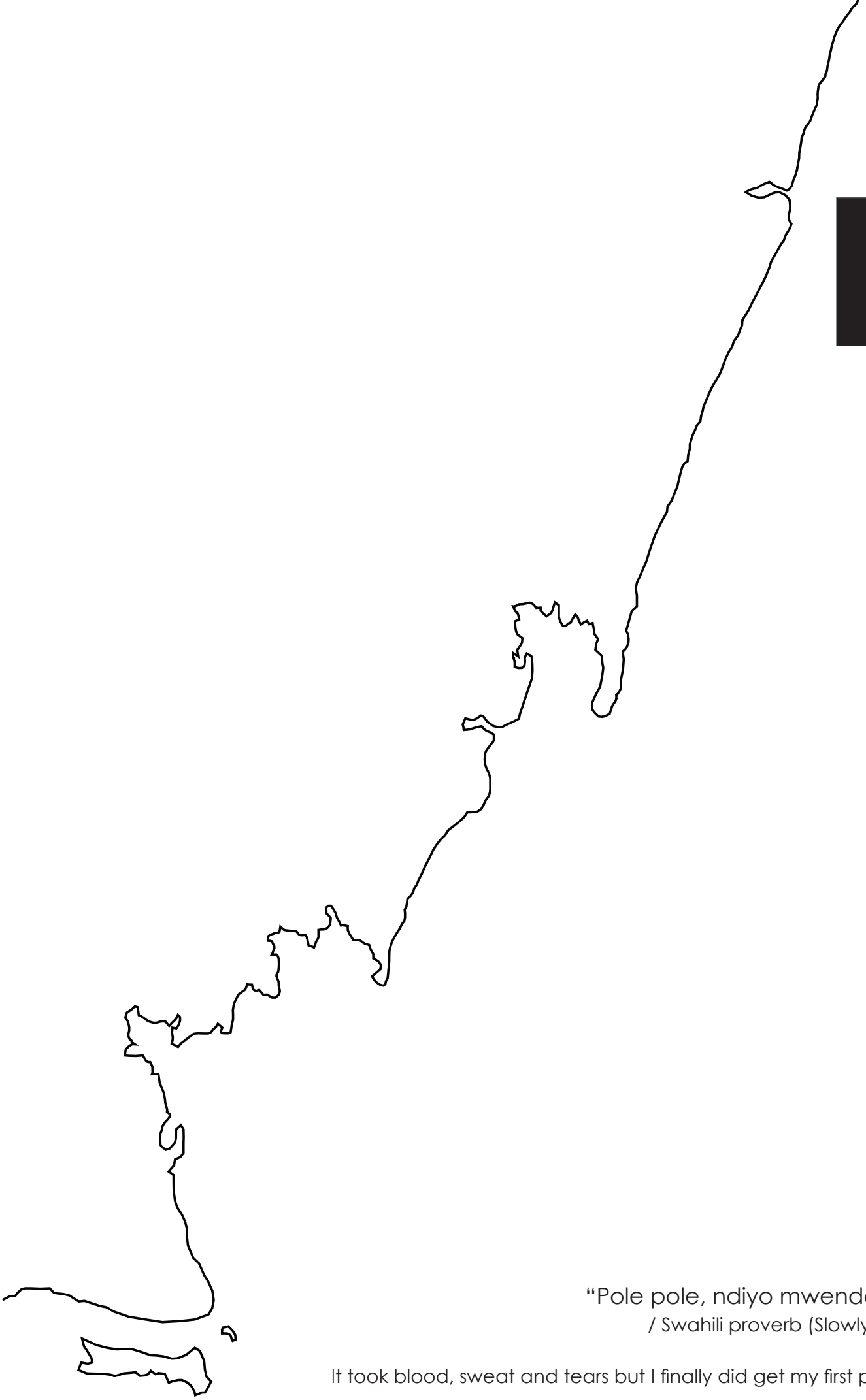

"Pole pole, ndiyo mwendo"

/ Swahili proverb (Slowly but surely)

It took blood, sweat and tears but I finally did get my first publication.

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Use of replanted mangroves as nursery grounds by shrimp communities in Gazi Bay, Kenya

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Abstract

This study quantitatively assessed the distribution of postlarval and juvenile shrimps in natural, degraded and replanted stands of *Sonneratia alba* mangroves in Gazi Bay, Kenya in 2002–2003. Two plantations (matrix and integrated) differing in historical status and planting strategy were studied. Sampling was conducted using stake nets (2 mm mesh), each net enclosing 9 m^2 of intertidal microhabitat. A total of 615 shrimps from 19 species/taxa were caught, including several penaeid species of major commercial importance. Penaeids dominated the catch (66%) followed by *Macrobrachium* spp. (16%) and *Acetes* sp. (6%). Shrimp abundance ranged from 0.42 to 10.0 ind. per net (9 m^2) for individual sites across spring tides and significant differences were detected between sites and over time ($p<0.001$). Results showed no significant difference in diversity of species/taxa between sites. However, multivariate analysis revealed significant differences in community assemblages between sites, except for the natural stand and integrated plantation. These two sites harbored higher abundances of the majority of all taxa caught. The observed distribution patterns are discussed with regard to measured environmental parameters such as elevation, structural complexity and sediment characteristics.

Keywords: mangrove; restoration; nursery ground; postlarval and juvenile shrimp; Penaeidae distribution pattern; stake net

1. Introduction

Increasing pressure on the world's mangrove resources by a number of anthropogenic activities has led to a worldwide up-surge of the number of reforestation programs initiated in the last decades (Field, 1996). Field (1998) lists three main reasons behind the majority of mangrove rehabilitation initiatives: conservation and landscaping, multiple use systems for high and sustainable yield and protection of coastal areas. However, regardless of primary motives, the progress of any mangrove rehabilitation scheme will ultimately depend on the successful re-establishment of essential ecological functions, underpinning the provision of goods and services from these ecosystems. Monitoring of the tree component, although a conspicuous and vital element in the mangrove ecosystem, is not enough to provide estimates of such functional diversity. To date, very few studies have focused on the return of ecosystem functions other than those directly associated with the trees (Al-Khayat and Jones, 1999; Macintosh, 2002; Morrisey et al., 2003). Apart from some information in Rönnbäck et al. (1999), no studies have, to our knowledge, provided quantitative data on the utilization of these rehabilitated habitats by larval or juvenile fish and shrimp.

The nursery role of mangroves is well established (e.g. Robertson and Duke, 1987; Vance et al., 1996; Primavera, 1998; Rönnbäck et al., 2002) and the proposed reasons why juveniles of many commercially

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important fish and penaeid shrimp species utilize these coastal forests have been food abundance, shelter from predation and the hydrodynamic ability of mangroves to retain immigrating larvae and juveniles (Robertson et al., 1992; Robertson and Blaber, 1992; Rönnbäck, 1999; Chong et al., 2001).

Studies on shrimp distributional pattern in mangrove systems have almost exclusively focused on penaeid shrimps, likely due to their immense importance as a commercial fishery resource in tropical and sub-tropical regions (Rönnbäck, 1999; Mwatha, 2002). Most studies have, however, been conducted in the open water habitats of the mangrove system, such as creeks, channels and adjacent mudflats. These studies have compiled an impressive amount of information on the population dynamics of several penaeid species, yet quantitative estimates of their distribution inside the forested mangrove habitat remain few and isolated (Vance et al., 1996, 2002; Rönnbäck et al., 1999, 2002; Meager et al., 2003). Despite abundant evidence in favor of the nursery function of mangroves for early life stages of many penaeid shrimp species, questions remain as to the amount of support different mangroves provide to commercial shrimp fisheries. Riverine, fringing and basin mangrove ecosystems may differ significantly in their supportive role for commercial stocks (Rönnbäck et al., 2002) and such issues need to be taken into account when planning and implementing rehabilitation programs.

The present study was conducted with the aim of quantitatively investigating the distribution of shrimp postlarvae and juveniles in two replanted, fringing monostands of *Sonneratia alba* in southern Kenya. The plantations differed with respect to the status of the area prior to planting as well as the density and structure of the plantation effort. The study also included comparisons of the plantations to a natural stand of *S. alba* and a previously forested, but since clear-cut area. Although the main focus of this paper is on penaeid shrimps, diversity of other shrimp taxa and differences in community assemblages associated with natural, replanted and deforested areas are also described and discussed.

2. Materials and methods

2.1. Study area

This study was conducted in fringing *Sonneratia alba* stands of differing age and status along the north western shore of Gazi Bay, Kenya (Fig. 1). Gazi Bay is located on the southern Kenyan coast at 4°25′S and 39°50′E. The inner estuary is sheltered from intense wave impact by shallow reefs at the mouth of the bay. Seasonal rains dominate the climate with two pronounced rainy seasons; a period of heavy rains from April to June (South East monsoon) and a period of lighter rains from October to November (North East monsoon). Total annual rainfall ranges between 1000 and 1600 mm and the salinity in the study area ranges from 24 to 26.5 during the SE monsoon (Kitheka, 1997). Gazi Bay has a semi-diurnal tidal regime with a tidal height at spring high tide ranging from approximately 2.0 to 4.0 m. Tidal currents vary and although currents of up to 0.6 m s^{-1} have been recorded current speed in the open areas of the bay are generally less than 0.25 m s^{-1} (Kitheka, 1997).

2.2. Sampling schedule and fishing methods

The field sampling was carried out on three spring tides; April–May 2002 (one spring tide) and April–May 2003 (two spring tides). The method of using stake nets to obtain quantitative measurements of shrimp density in mangrove habitats was first developed by Vance et al. (1996) (with reference to block net sampling of fish by Thayer et al. (1987)) and later modified by Rönnbäck et al. (1999, 2002). The method employed in this study is the one described in Rönnbäck et al. (2002). Net pens measuring 3 × 3 m, thus enclosing 9 m^2, were set using four corner poles and the lower end of the net was secured in the mud. At high tide the nets were raised and catch was collected the following low tide. All nets had a stretched mesh size of 2 mm. Four different sites were included in the investigation; a natural stand, site N, a clear-cut, degraded area, site D, and two different areas of planted mangroves, site MP and site IP (Fig. 1). The size of the individual sites ranged from 1700 (MP) to 10,800 (N) m^2 (Table 1). The two plantations differed with respect to the method of planting used. Site MP (matrix plantation) was planted on a clear-cut strip of fringing mangrove in a 1 × 1 m matrix, which has resulted in a dense monostand of *S. alba* with a relatively high degree of canopy cover and a more homogenous root complexity throughout the site than plantation IP. The latter site (integrated plantation (IP)) was planted in a degraded but partly forested area adjacent to a natural stand of *S. alba*. Consequently, this site had a more heterogeneous appearance with natural canopy gaps and a higher variability in root complexity due to the diversity in age of the existing trees. Both plantations were initiated in 1994.

Penaeid shrimp larvae are reported to enter coastal areas through diurnal vertical migration coupled to inshore currents, while postlarval migration is closely linked to lunar phases and tidal amplitudes (reviewed in Garcia and Le Reste, 1981; Dall et al., 1990). Furthermore, it has been shown by Staples and Vance (1979) and Stoner (1991) that shrimp catchability significantly increases with night sampling due to a more active behavior, possibly as a result of feeding (Vance, 1992; Primavera and Lebata, 1995). Sampling was therefore conducted on spring tides, all nets deployed at night, around maximum high tide, and catch collected at dawn

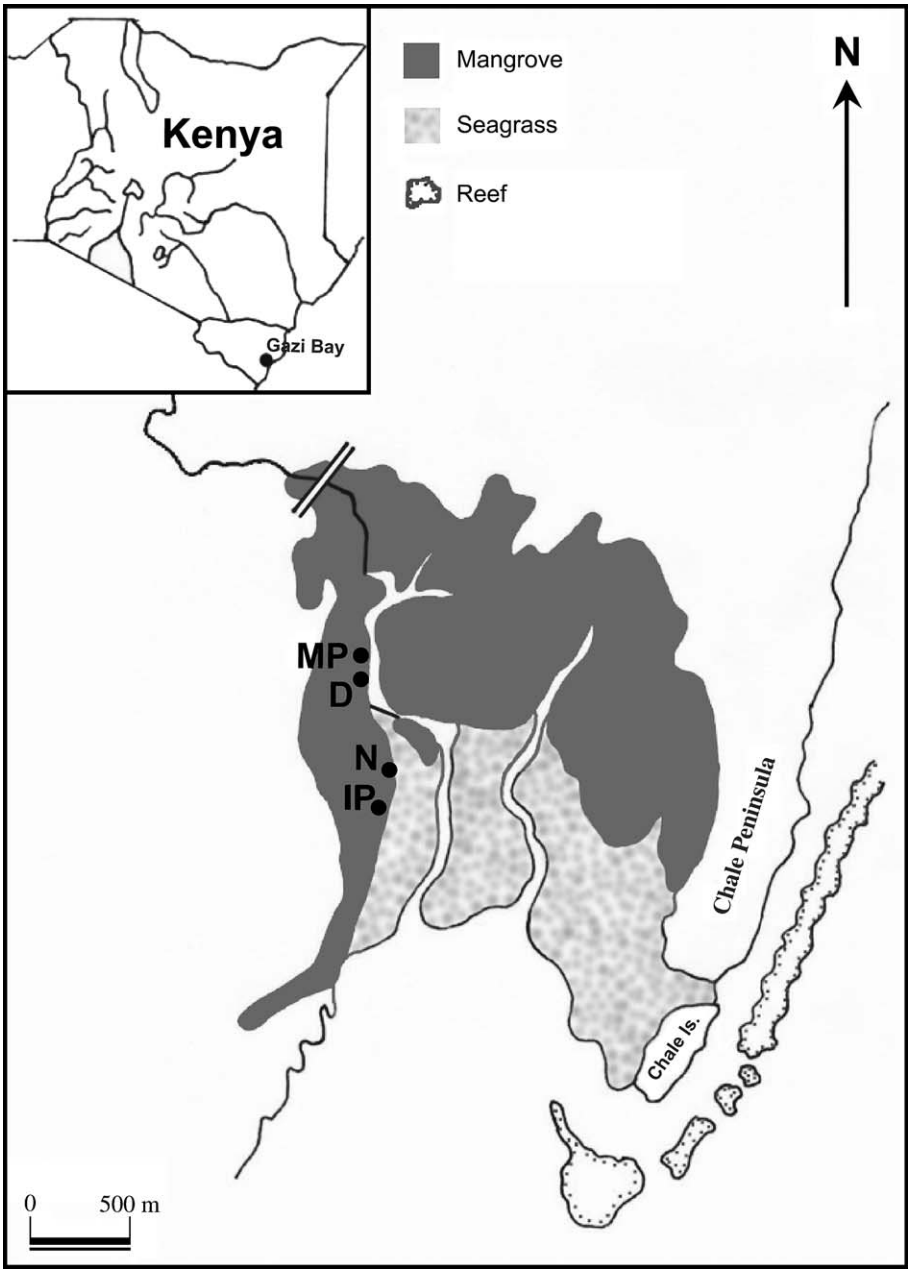

Fig. 1. Map of study area, Gazi Bay, Kenya. The area is located on the southern Kenyan coast at 4°25'S and 39°50'E. N = natural stand, IP = integrated plantation, MP = matrix plantation and D = denuded plot.

Table 1
Physical parameters of mangrove habitats sampled in Gazi Bay, Kenya. Area, relative site elevation, structural complexity (ratio of mangrove root surface to sediment area), organic content, percent finest fraction of sediment (<0.075 mm), sediment chl *a* content, and range of water depth at high tide for each studied site; N, natural; IP, integrated plantation; MP, matrix plantation; D, deforested site (mean ± SE)

Site	Total area (m^2)	Elevation (m)	Water depth at high tide (m)	Structural complexity	Sediment organic content (%)	Fine sediment content (%)	Chl a sediment content (mg m^{-2})
N	10800	0.14	1.16–1.51	0.44 ± 0.14	7.9 ± 1.6	3.7 ± 0.5	66.4 ± 8.7
IP	7900	0	1.30–1.65	0.27 ± 0.10	14.3 ± 1.1	5.7 ± 0.7	77.1 ± 7.9
MP	1700	0.37	0.80–1.45	0.23 ± 0.09	9.2 ± 1.8	9.6 ± 0.7	94.6 ± 7.4
D	3700	0.37	0.80–1.45	0	1.6 ± 0.3	2.2 ± 0.3	62.0 ± 8.3

as the tide receded. Two sites were always sampled simultaneously with four nets deployed in each site. The same two sites were sampled for two or three consecutive nights resulting in a total of eight or 12 nets per site and spring tide. All sites were sampled on each spring tide, and when consecutive spring tides were sampled the order in which the sites were sampled was switched for the second sampling occasion so as to avoid any bias from two sites always being sampled on the first days of the rising spring tide. Shrimps were sorted from other crustaceans, fish and detritus and preserved in 8% seawater-formalin. All individuals were then identified to species or lowest taxonomic group using Joubert (1965) and Kensley (1972).

2.3. Sampling of environmental parameters

Relative site elevation was measured by simultaneously measuring tidal height of all sites at a given time. Ten sediment samples were taken randomly within each site using a glass test tube in order to establish chlorophyll a content of the sediment. The upper 5 mm of the core were transferred to a clean glass test tube wrapped in aluminum foil and a fixed volume of 90% acetone was added. The samples were transported to the laboratory and analyzed for chlorophyll *a* content using Standardized Swedish Methods (Svensk Standard SS028146). Another ten randomly selected samples were taken with a plastic corer (26.7 mm diameter) dried and analyzed to determine mean grain size according to Morgans (1956) and sediments were classified based on the Wentworth scale as described in Boggs (2001). Within each area enclosed by a net, four cores (26.7 mm diameter, 1.5 cm depth) were taken for analysis of sediment organic content. Cores were dried at 60 °C to constant weight, ashed in a muffle furnace at 550 °C for 5 h and weighed again. Organic content is expressed as percentage of the initial dry weight.

Structural complexity of the forested habitats was calculated as a ratio between root surface area and sediment surface area. These measurements were obtained by measuring the base and height of roots in a sub-sample (1 m^2) of the area enclosed by each net and then treating each root as a perfect cone for which the surface area was computed.

2.4. Statistical analysis

Biotic data similarity matrices were constructed using the Bray–Curtis similarity coefficient on non-standardized 4th root transformed data. Formal significance tests were conducted using ANOSIM permutation tests for multivariate data (Clarke and Green, 1988) and two-way Anova for univariate comparisons of selected species. All shrimp data was tested statistically for the effect of consecutive sampling, but as there was no trend or significant differences between catches per net and day, nets were pooled within sites and individual spring-tide periods served as temporal units. Data for individual nets was also checked to eliminate the possibility that crab predation consistently lowered the catches in certain nets due to the order of catch collection. No such trend was detected. For two-way crossed ANOSIM, as well as two-way Anova, factors time and site were used for analysis of species assemblages and individual species distribution, respectively. Univariate analysis was preceded by $(x + 0.01)^{0.1}$ transformation of abundance data. Further exploration of species responsible for similarities between sites was conducted through a similarities procedure (SIMPER; Warwick et al., 1990). Multivariate analyses were run using the PRIMER 5 software and Canoco 4.5. Environmental data were tested for significant differences between sites using parametric and non-parametric Anova and Mann–Whitney *U*-tests or Tukey's test for post-hoc unplanned comparisons. For multiple comparisons significance levels were adjusted using the Bonferroni method (Rice, 1989). Univariate statistics were computed with STATISTICA 6.0.

3. Results

3.1. Habitat characteristics

The integrated plantation (IP) had the lowest elevation followed by the adjacent natural stand (N). These habitats thus had the largest water depth at high tide (Table 1). Depth differences of up to 0.20 m on consecutive nights were common. The higher elevation of sites MP and D and their position approximately 500 m further up the creek resulted in these sites being inundated approximately 80 min less every tidal cycle. The clear-cut area was characterized by coarser sediments, predominantly sand, while the forested sites had a higher percentage of the fine sediment fraction (<0.075 mm) with highest values found in the matrix plantation (Table 1). A Kruskal–Wallis ANOVA showed significant differences between sites with respect to this parameter ($p<0.001$) and post-hoc comparisons with Mann–Whitney *U*-test showed significant differences ($p<0.05$) between all sites except sites IP and N. Sediment organic content also varied between sites (1.6–14.3%) with the largest mean values in the integrated plantation (IP) (Table 1). This variable, along with chlorophyll *a* levels in surface sediments, was found to differ significantly between study areas ($p<0.001$). Post-hoc tests showed that all pair-wise between site comparisons were significant ($p<0.05$) except for MP and N for sediment organic content, while chlorophyll *a* levels were significantly higher in the matrix plantation ($p<0.05$). Structural complexity ($p=0.38$) did not differ significantly between forested sites although a trend

could be seen with the highest structural complexity found in the natural stand (N), and the lowest in the matrix plantation (MP). Fewer but markedly larger pneumatophores, associated with a few large trees, in site IP and N contributed to the higher values of structural complexity compared to MP. The latter had smaller but more numerous pneumatophores, creating a different, yet possibly just as complex micro-environment. Worth noting is that additional structural complexity provided by debris such as fallen twigs, logs and branches were not included in the complexity measure. Occurrence of such elements was higher in the natural stand likely resulting in an underestimation of microhabitat complexity in this site compared to the plantations. No pneumatophores or other structural components existed in the clear-cut area.

3.2. Shrimp abundance and species richness

A total of 615 shrimps from 19 different species/taxa were caught. Penaeid shrimps dominated the catch (66%), followed by *Macrobrachium* spp. (16%), *Acetes* sp. (6%) and other carideans (11%) (Fig. 2). The penaeid shrimp community was dominated by post-larval and juvenile life stages.

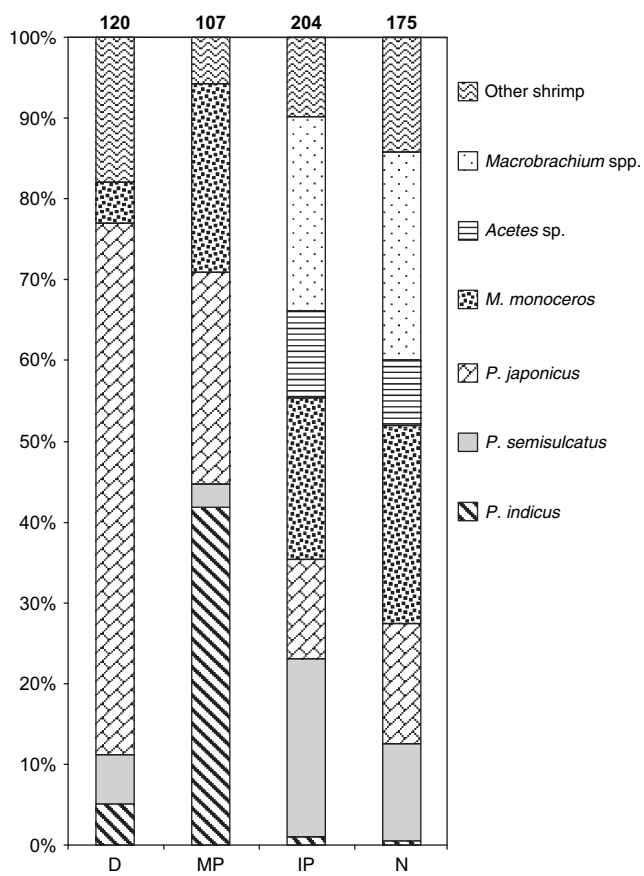

Fig. 2. Percentage contribution of shrimp species to total shrimp abundance in *Sonneratia alba*, Gazi Bay. Values are averaged over all sampling occasions. Number of shrimps upon which calculations were made are indicated at the top of each site column. N = natural stand, IP = integrated plantation, MP = matrix plantation and D = deforested area.

No pronounced differences in species richness among sites were found. Instead diversity measures seemingly differed more between years (Table 2). The total number of shrimp species/taxa encountered at each site was also lower in the matrix plantation (eight taxa) compared to the other sites (10–13 taxa). In addition, the natural stand and integrated plantation had a more even relative distribution by species/taxa to total abundance (Fig. 2).

The variability of shrimp abundance within sites was consistently high in each spring tide, and mean daily shrimp abundance ranged from 0.42 (site D) to 10 (site MP) ind per net (9 m^2) (Table 3) There were also significantly lower total shrimp abundances in 2002, particularly in sites MP and D (Table 3). These low values are the main factor responsible for the significant difference in total shrimp abundance between sites and over time (Table 4). The same trend generally applies for individual penaeid shrimp species as well as *Acetes* sp. and *Macrobrachium* spp. in 2003 (Table 3). Two species deviate from the above pattern; *Penaeus indicus* and *P. japonicus*, which in 2003 were found in higher numbers in sites MP and D, respectively.

Results from a two-way Anova of abundance values for six selected species are presented in Table 4 and showed that for all tested species sites differed significantly in abundance while difference in abundance over time was significant for all species except *Metapenaeus monoceros* and *Acetes* sp. Only *P. indicus* and *P. japonicus* showed a significant interaction between time and site. Tukey post-hoc comparisons showed abundance of *P. indicus* in site MP to be significant higher ($p < 0.05$) than all other sites while there were also differences in *P. indicus* abundance of MP between years due to increasing values in 2003. Similarly, abundance of *P. japonicus* was significantly higher in site D ($p < 0.05$) than all other plots while increasing abundance values in 2003 at this site resulted in a significant time × site interaction (Table 4).

Table 2
Species richness (Margalef's index *R*) and Shannon–Wiener diversity index (*H′*) for juvenile shrimps caught in fringing *Sonneratia alba* mangrove stands in Gazi Bay, Kenya. Values are averaged over sites and years. Natural (site N), replanted (site MP and IP) and denuded (site D)

	R		*H′*	
	Avg	SE	Avg	SE
Site				
N	1.24	0.11	0.74	0.10
IP	1.06	0.10	0.73	0.09
MP	0.67	0.11	0.74	0.10
D	1.03	0.13	0.63	0.11
Year				
2002	0.84	0.12	0.46	0.08
2003	1.10	0.07	0.73	0.06

Table 3
Mean abundance (±SE) per net (9 m^2) of shrimps sampled in fringing mangroves in Gazi Bay, Kenya, over three sampling seasons in 2002 and 2003 (spring tide 1 and 2). Replanted (IP and MP), natural (N) and clear-cut (D) sites of *Sonneratia alba*. $n = 12$

Shrimp species	N	IP	MP	D
Penaeus indicus				
2002	0	0	0	0.08±0.08
2003(1)	0.08±0.08	0.17±0.11	0.50±0.23	0.08±0.08
2003(2)[a]	0	0	4.63±2.35	0.50±0.33
P. japonicus				
2002	0.67±0.28	0.67±0.28	0.08±0.08	0
2003(1)	1.00±0.65	1.00±0.30	0.08±0.08	4.08±1.08
2003(2)[a]	0.75±0.41	0.63±0.42	3.13±1.44	3.50±0.78
P. semisulcatus				
2002	0.08±0.08	1.50±0.88	0	0
2003(1)	1.25±0.92	1.33±0.51	0.17±0.11	0.25±0.18
2003(2)[a]	0.63±0.18	1.38±0.63	0.13±0.13	0.50±0.27
Metapenaeus monoceros				
2002	0.17±0.11	2.00±1.15	0.33±0.26	0.17±0.11
2003(1)	1.75±1.10	0.50±0.19	0.58±0.29	0.25±0.13
2003(2)[a]	2.38±1.50	1.38±0.46	1.63±0.56	0.13±0.13
Total Penaeid				
2002	2.08±0.48	4.17±1.47	0.42±0.26	0.25±0.18
2003(1)	4.33±2.69	3.08±0.65	1.33±0.45	4.92±1.12
2003(2)[a]	3.75±1.49	3.63±0.91	9.50±3.63	4.63±0.94
Acetes sp.				
2002	0.08±0.08	0.25±0.18	0	0
2003(1)	0.83±0.46	1.33±0.58	0	0
2003(2)[a]	0.38±0.18	0.38±0.26	0	0
Macrobrachium spp.				
2002	1.00±0.35	2.08±0.68	0.17±0.17	0.17±0.11
2003(1)	0.67±0.43	0.42±0.34	0	0
2003(2)[a]	3.13±1.51	2.38±1.22	0	0
Total shrimp community				
2002	2.08±0.48	6.58±1.66	0.58±0.29	0.42±0.26
2003(1)	6.92±4.43	5.50±1.10	1.67±0.45	5.92±1.36
2003(2)[a]	8.50±3.01	7.75±2.38	10.0±3.82	5.75±1.18

[a] $n = 8$.

Post-hoc comparisons for *Macrobrachium* spp. and *Acetes* sp. showed a general pattern where sites IP and N had significantly higher abundances ($p<0.05$) compared to D and MP over both years.

3.3. Multivariate analysis of species assemblages

An ANOSIM (analysis of similarities) for a two-way crossed design was performed. The factors were time of sampling and site. Global tests showed weak differences among sites ($R = 0.187$, $p<0.001$) with sites IP and N being similar in terms of shrimp species composition and abundance, while site D and MP differed from both IP and N ($p<0.05$). Site MP and D also differ from each other ($p<0.01$). SIMPER analysis showed *Macrobrachium* spp. to be relatively strongly associated with the integrated plantation and natural stand as this species, together with *Acetes* sp. were essentially only found in these sites (Tables 3 and 5). *Penaeus japonicus* characterized the species assemblage for the denuded area, while *Metapenaeus monoceros* showed affinity to forested sites and *P. semisulcatus* was found predominantly in site IP and N (Tables 3 and 5). Comparisons between sampling occasions showed no significant differences. The low values of global R are most likely due to the highly variable and patchy presence of species such as *P. indicus*, which is also the reason this species does not appear in Table 5.

3.4. Species distributions and environmental parameters

A canonical correspondence analysis (CCA) with unrestrained permutations was run and inter-species relationships plotted against percentage sediment organic content, mg chlorophyll a m^{-2} as well as percentage fine fraction of total sediment (<0.075 mm) (Fig. 3).

Table 4
ANOVA test summary for total shrimp abundance as well as abundance of *P. indicus*, *P. semisulcatus*, *P. japonicus*, *M. monoceros*, *Macrobrachium* spp. and *Acetes* sp. with spring tide (time) and site as factors

Source of variation	df	SS	MS	*F*	*p*
Total shrimp abundance					
Time	2	1.407	0.704	18.860	<0.001
Site	3	0.725	0.242	6.476	<0.001
Time × site	6	0.772	0.129	3.447	0.004
Error term	116	4.328	0.037		
Penaeus indicus					
Time	2	0.178	0.89	4.997	0.008
Site	3	0.335	0.112	6.268	<0.001
Time × site	6	0.310	0.052	2.899	0.011
Error term	116	2.069	0.018		
P. semisulcatus					
Time	2	0.310	0.155	4.980	0.008
Site	3	0.597	0.199	6.392	<0.001
Time × site	6	0.067	0.011	0.360	0.902
Error term	116	3.610	0.031		
P. japonicus					
Time	2	0.718	0.359	10.702	<0.001
Site	3	0.601	0.202	6.021	<0.001
Time × site	6	1.494	0.249	7.427	<0.001
Error term	116	3.889	0.034		
Metapenaeus monoceros					
Time	2	0.255	0.127	3.043	0.052
Site	3	0.347	0.116	2.760	0.045
Time × site	6	0.233	0.039	0.927	0.478
Error term	116	4.860	0.042		
Machrobrachium spp.					
Time	2	0.351	0.176	5.941	0.003
Site	3	1.305	0.435	14.715	<0.001
Time × site	6	0.280	0.047	1.576	0.160
Error term	116	3.430	0.030		
Acetes sp.					
Time	2	0.100	0.050	2.400	0.095
Site	3	0.277	0.092	4.409	0.006
Time × site	6	0.133	0.019	0.899	0.498
Error term	116	2.432	0.021		

The 1st and 2nd axis of the CCA explained 81.8% of the total variance in distribution of species and environmental variables. The CCA reinforces the pattern observed above, with *Acetes* sp., *Macrobrachium* spp. and *Penaeus semisulcatus* being associated with the natural stand and integrated plantation, *Penaeus indicus* with the matrix plantation, *Metapenaeus monoceros* with all forested sites and *Penaeus japonicus* with the deforested site.

4. Discussion

The variability in shrimp catches among nets at any given site was quite large. Certain nets yielded consistently higher catches of shrimp, a phenomena also observed by Vance et al. (2002), which they attributed to several parameters including local topography and substrate elevation resulting in highly localized water currents in the mangrove creeks. Vance et al. (2002) also noted a certain degree of predation on shrimps caught in the nets by fish and suggested this to be a possible source of underestimation of shrimp abundance. Predation on shrimps by fish and crabs, which are abundant at all sites in the present study, was observed. Hence this may have led to a similar overall underestimation of shrimp abundance although the method of catch collection was designed to minimize such predation.

Shrimp catches were considerably lower in 2002 compared to 2003 samples. Such natural yearly fluctuations in shrimp abundance have also been observed for penaeids in both Australia and Malaysia (Vance et al., 1998; Ahmad Adnan et al., 2002). In both 2002 and 2003 a similar pattern of shrimp abundance emerged, however, with higher abundances of certain species in certain sites indicating reoccurring preference for these sites over time by a particular species.

Comparisons of individual species abundances showed that some species such as *Peneus japonicus* and *P. indicus* exhibited a selective preference for the denuded site and the matrix plantation respectively. This pattern is also supported by analysis of similarities showing differences (although weak) in species composition between study areas. The low average similarity values within sites reflect the variance in species occurrence and abundance. Worth noting is that for all forested sites (IP, N and MP) at least three species of shrimps are responsible for 80% of the similarity within sites, whereas for the clear-cut site only one species, *P. japonicus*, accounts for 80% similarity (Table 5, Fig. 2). Many juvenile penaeid species are known to prefer structurally complex micro-habitats as shelter from predation (Primavera and Lebata, 1995; Primavera, 1997; Macia et al., 2003) and this may explain the preference for these forested sites. In all comparisons including the denuded site, *P. japonicus* ranked as the most important characterizing species. In site comparisons including the natural stand, *Macrobrachium* spp. ranked high and could be considered a potential characterizing species.

Penaeus semisulcatus, *Acetes* sp. and *Macrobrachium* spp. were found to be strongly associated with the integrated plantation and the natural stand (Fig 2) and univariate results further support this. *P. semisulcatus* is a penaeid species whose juveniles are known to occur primarily in seagrass beds (de Freitas, 1986; Loneragan et al., 1994; Macia, 2005). The close proximity to adjacent seagrass beds in Gazi may thus explain the higher numbers and more regular occurrence of the species at these sites. To our knowledge no studies exist on habitat preferences and behavioral ecology for *Acetes* sp. and *Macrobrachium* spp. in mangrove environments. Meager et al. (2003) did, however, study other species of these genera and found them in higher abundances in sites with lower elevation, i.e. at greater water depths,

Table 5
Shrimp species responsible for similarities within and dissimilarities between sites of *Sonneratia alba* mangroves in Gazi Bay, Kenya based on shrimp abundance. Natural (site N), replanted (site IP and MP) and denuded (site D)

Site	Species	δ_i/SD(δ_i)	Contribution (%)	Cumulative contribution (%)	Average similarities
Species responsible for observed similarity between sites					
N	*Macrobrachium* spp.	0.66	41.63	41.63	30.50
	P. japonicus	0.50	25.63	67.26	
	M. monoceros	0.42	15.63	83.19	
IP	*M. monoceros*	0.48	24.60	24.60	29.48
	P. semisulcatus	0.51	22.98	47.57	
	Macrobrachium spp.	0.42	20.79	68.36	
	P. japonicus	0.47	20.13	88.49	
MP	*M. monoceros*	0.60	55.31	55.31	26.86
	P. indicus	0.41	24.64	79.95	
	P. japonicus	0.35	16.87	96.83	
D	*P. japonicus*	1.39[a]	82.35	82.35	39.88
		Dissimilarites/SD	Contribution (%)	Cumulative contribution (%)	Average dissimilarities
Species responsible for observed dissimilarity between sites					
IP, N	*Macrobrachium* spp.	1.02	18.79	18.79	69,71
	M. monoceros	0.96	16.48	35.27	
	P. japonicus	0.94	15.55	50.82	
IP, MP	*M. monoceros*	0.99	17.95	17.95	78,20
	P. japonicus	0.95	15.57	33.53	
	Macrobrachium spp.	0.76	14.60	48.12	
N, MP	*Macrobrachium* spp.	1.03[b]	18.25	18.25	80,22
	M. monoceros	1.00	18.02	36.28	
	P. japonicus	0.98	16.22	52.49	
IP, D	*P. japonicus*	1.11[b]	21.56	21.56	74,87
	M. monoceros	0.87	14.37	35.93	
	P. semisulcatus	0.93	14.00	49.94	
N, D	*P. japonicus*	1.12[b]	21.64	21.64	73,83
	Macrobrachium spp.	1.02[b]	17.51	39.15	
	M. monoceros	0.87	13.39	52.54	
MP, D	*P. japonicus*	1.28[b]	27.76	27.76	75,15
	M. monoceros	0.96	18.89	46.65	
	P. indicus	0.84	15.60	62.25	

[a] The species potentially characterizes the species assemblage within a site.
[b] A possible discriminating species between sites.

which also distinguishes the natural stand and integrated plantation in Gazi Bay.

Most individuals of *Penaeus indicus* were caught in the matrix plantation. This species has been shown to have an almost absolute preference for mangroves over unvegetated habitats (Rönnbäck et al., 2001), which may explain its low abundance in the deforested site, but not the extreme low densities in the natural stand and integrated plantation. Differences in sediment properties among forested sites are also unlikely to solely explain this pattern (Fig. 3), as *P. indicus* has previously been found not to select for mangrove microhabitats differing in organic content or proportion of fine sediment (Rönnbäck et al., 2001). The distribution patterns of *Penaeus japonicus* has not been extensively investigated in natural environments but studies conducted show this species to have a preference for primarily bare, sandy areas (de Freitas, 1986; Macia, 2005). The same author found that juveniles of this species were able to bury themselves very efficiently in the substratum and possibly able to tolerate quite high temperatures on the exposed sandflats due to this fact. This reported behavior combined with pigmentation providing good camouflage in the sand (personal observation) supports the distribution pattern of *P. japonicus* as the only penaeid species found in significant numbers in the deforested site. This observed distribution pattern may be linked to a preference for sandier substrates (in this

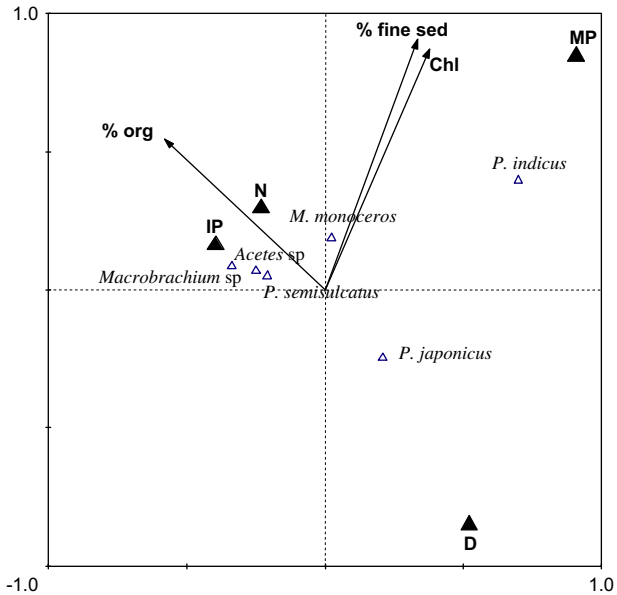

Fig. 3. Canonical Correspondence Analysis (CCA) of shrimp abundance and environmental variables. Biplot with 1st and 2nd axis accounting for 81.8% of total variance of species distribution. Sites are plotted as nominal variables; N = natural stand, IP = integrated plantation, MP = matrix plantation and D = deforested area.

case a direct result of deforestation) rather than active selection of unvegetated areas.

Metapenaeus monoceros has been found to be widespread, occurring in a variety of habitats (Hughes, 1966; de Freitas, 1986; Rönnbäck et al., 2002). However, postlarvae of this species have been reported to have a selective preference for unvegetated shallows while juveniles and subadults were equally distributed among mangroves and adjacent sandflats in Mozambique (Rönnbäck et al., 2002). The present study found *M. monoceros* to be moderately represented in all sites, although with a preference for forested areas. These sites all have a higher degree of fine sediments and organic content compared to the denuded site. Macia (2005) also found this species to prefer fine sediments (muddy), which may be one determinant for habitat choice.

The pattern of distribution of different species of shrimp among the studied sites may be a result of selective preferences of species for certain habitats as suggested by some authors (Hughes, 1966; de Freitas, 1986). However, it is also possible that the observed pattern is a result of survival rather than active habitat selection, in this case indicating a higher level of survival for a larger number of species in the replanted and natural stands of mangroves in Gazi Bay as compared to the deforested area.

5. Conclusions

Slightly higher abundances of the majority of shrimp species/taxa were caught in the integrated and natural stand of *Sonneratia alba* studied. Although there were no noticeable differences in species diversity between areas these two sites also had a more even distribution of species in terms of percentage composition of catch. They also harbored a higher diversity of penaeid species likely due to greater heterogeneity in terms of structural complexity as well as longer inundation time. There were significant differences in overall shrimp abundance between forested and unvegetated sites, however, catches were also highly variable within microhabitats, which means only modest conclusions should be drawn from this. This suggests that detecting differences in microhabitat preferences for shrimps and evaluating replanted habitat use in the field may call for an even larger number of samples or investigations focusing on larger spatial scales than in this study. However, increasing the spatial scale of investigation often results in variations in physical factors confounding the sampling design. Hence, ideally, future mangrove planting projects should take such aspects into account in order to increase the possibilities of evaluating the return of related ecological functions.

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References

Ahmad Adnan, N., Loneragan, N.R., Conolly, R.M., 2002. Variability of, and the influence of environmental factors on, the recruitment of postlarval and juvenile *Penaeus merguiensis* in the Matang mangroves of Malaysia. Marine Biology 141, 241–251.

Al-Khayat, J.A., Jones, D.A., 1999. A comparison of the macrofauna of natural and replanted mangroves in Quatar. Estuarine, Coastal and Shelf Science 49 (Supplement A), 55–63.

Boggs Jr., S., 2001. Principles of Sedimentology and Stratigraphy, second ed. Prentice Hall, London, 774 pp.

Chong, V.C., Low, C.B., Ichikawa, T., 2001. Contribution of mangrove detritus to juvenile prawn nutrition: a dual stable isotope study in a Malaysian mangrove forest. Marine Biology 138, 77–86.

Clarke, K.R., Green, R.H., 1988. Statistical design and analysis for a 'biological effects' study. Marine Ecology and Progress Series 46, 213–226.

Dall, W., Hill, B.J., Rothlisberg, P.C., Staples, D.J., 1990. The biology of the Penaeidae. In: Blanter, J.H.S., Soutward, A.J. (Eds.), Advances in Marine Biology 27, 1–489.

de Freitas, A.J., 1986. Selection of nursery areas by six Southeast African Penaeidae. Estuarine, Coastal and Shelf Science 23, 901–908.

Field, C.D., 1996. Restoration of Mangrove Ecosystems. International Society for Mangrove Ecosystems, Okinawa, 250 pp.

Field, C.D., 1998. Rehabilitation of mangrove ecosystems: an overview. Marine Pollution Bulletin 37 (8–12), 383–392.

Garcia, S., Le Reste, L., 1981. Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. FAO Fisheries Technical Paper 203, pp. 1–215.

Hughes, D.A., 1966. Investigations of the 'nursery area' and habitat preferences of juvenile penaeid prawns in Mozambique. Journal of Applied Ecology 3, 349–354.

Joubert, L.S., 1965. A preliminary report on the penaeid prawns of Durban Bay. South African Association for Marine Biological Research, Oceanographic Research Institute, Durban. Investigational Report of the Oceanographic Research Institute 11, 1–32.

Kensley, B., 1972. Shrimps and Prawns of Southern Africa. South African Museum, Cape Town, 68 pp.

Kitheka, J.U., 1997. Coastal tidally-driven circulation and the role of water exchange in the linkage between tropical coastal ecosystems. Estuarine, Coastal and Shelf Science 45, 177–187.

Loneragan, N.R., Kenyon, R.A., Haywood, M.D.A., Staples, D.J., 1994. Population dynamics of juvenile tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) in seagrass habitats of the western Gulf of Carpentaria, Australia. Marine Biology 119, 133–143.

Macia, A., 2005. Juvenile penaeid shrimp density, spatial distribution and size composition in four adjacent habitats within a mangrove fringed bay on Inhaca Island, Mozambique. Western Indian Ocean Journal of Marine Science, in press.

Macia, A., Abrantes, K.G.S., Paula, J., 2003. Thorn fish *Terapon jarbua* (Forskal) predation on juvenile white shrimp *Penaeus indicus* H. Milne Edwards and brown shrimp *Metapenaeus monoceros* (Fabricius): the effect of turbidity, prey density, substrate type and pneumatophore density. Journal of Experimental Marine Biology and Ecology 291 (1), 29–56.

Macintosh, D.J., Ashton, E.C., Havanon, S., 2002. Mangrove rehabilitation and intertidal biodiversity: a study in the Ranong mangrove ecosystem, Thailand. Estuarine, Coastal and Shelf Science 55, 331–345.

Meager, J.J., Vance, D.J., Williamson, I., Loneragan, N.R., 2003. Microhabitat distribution of juvenile *Penaeus merguiensis* de Man and other epibenthic crustaceans within a mangrove forest in subtropical Australia. Journal of Experimental Marine Biology and Ecology 294, 127–144.

Morgans, J.F.C., 1956. Notes on the analysis of shallow-water soft substrata. Journal of Animal Ecology 25 (2), 367–387.

Morrisey, D.J., Skilleter, G.A., Ellis, J.I., Burns, B.R., Kemp, C.E., Burt, K., 2003. Differences in benthic fauna and sediment among mangrove (*Avicennia marina* var. *australasica*) stands of different ages in New Zealand. Estuarine, Coastal and Shelf Science 56, 581–592.

Mwatha, G.K., 2002. Assessment of the prawn fishery, bycatch, resource use conflicts and performance of the turtle excluder device in Kenya. In: Current Status of the Trawl Fishery of Malindi-Ungwana Bay, KMFRI Technical Report. Kenya, pp. 44–66.

Primavera, J.H., 1997. Fish predation on mangrove-associated penaeids. The role of structures and substrate. Journal of Experimental Marine Biology and Ecology 215, 205–216.

Primavera, J.H., 1998. Mangroves as nurseries: shrimp populations in mangrove and non-mangrove habitats. Estuarine, Coastal and Shelf Science 46, 457–464.

Primavera, J.H., Lebata, J., 1995. Diel activity patterns in *Metapenaeus* and *Penaeus* juveniles. Hydrobiologia 295, 295–302.

Rice, W.R., 1989. Analyzing tables of statistical sets. Evolution 43, 223–225.

Robertson, A.I., Alongi, D.M., Boto, K.G., 1992. Food chains and carbon fluxes. In: Robertson, A.I., Alongi, D.M. (Eds.), Tropical Mangrove Ecosystems (Coastal and Estuarine Studies). American Geophysical Union, Washington, DC, pp. 293–326.

Robertson, A.I., Blaber, S.J.M., 1992. Plankton, epibenthos and fish communities. In: Robertson, A.I., Alongi, D.M. (Eds.), Tropical Mangrove Ecosystems (Coastal and Estuarine Studies). American Geophysical Union, Washington, DC, pp. 173–224.

Robertson, A.I., Duke, N.C., 1987. Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Marine Biology 96, 193–205.

Rönnbäck, P., Macia, A., Almqvist, G., Schultz, L., 2001. Do penaeid shrimps have a preference for mangrove habitats? Distribution pattern analysis on Inhaca Island, Mozambique. Estuarine, Coastal and Shelf Science 55, 427–436.

Rönnbäck, P., Troell, M., Kautsky, N., Primavera, J.H., 1999. Distribution pattern of shrimps and fish among Avicennia and Rhizophora microhabitats in the Pagbilao mangroves, Philippines. Estuarine, Coastal and Shelf Science 48, 223–234.

Staples, D.J., Vance, D.J., 1979. Effect of changes in catchability on sampling of juvenile and adolescent banana prawns, *Penaeus merguiensis* de Man. Australian Journal of Marine and Freshwater Research 30, 511–519.

Stoner, A.W., 1991. Diel variation in the catch of fishes and penaeid shrimps in a tropical estuary. Estuarine, Coastal and Shelf Science 33 (1), 57–69.

Thayer, G.W., Colby, D.R., Hettler Jr., W.F., 1987. Utilization of the red mangrove prop root habitat by fishes in South Florida. Marine Ecology Progress Series 35, 25–38.

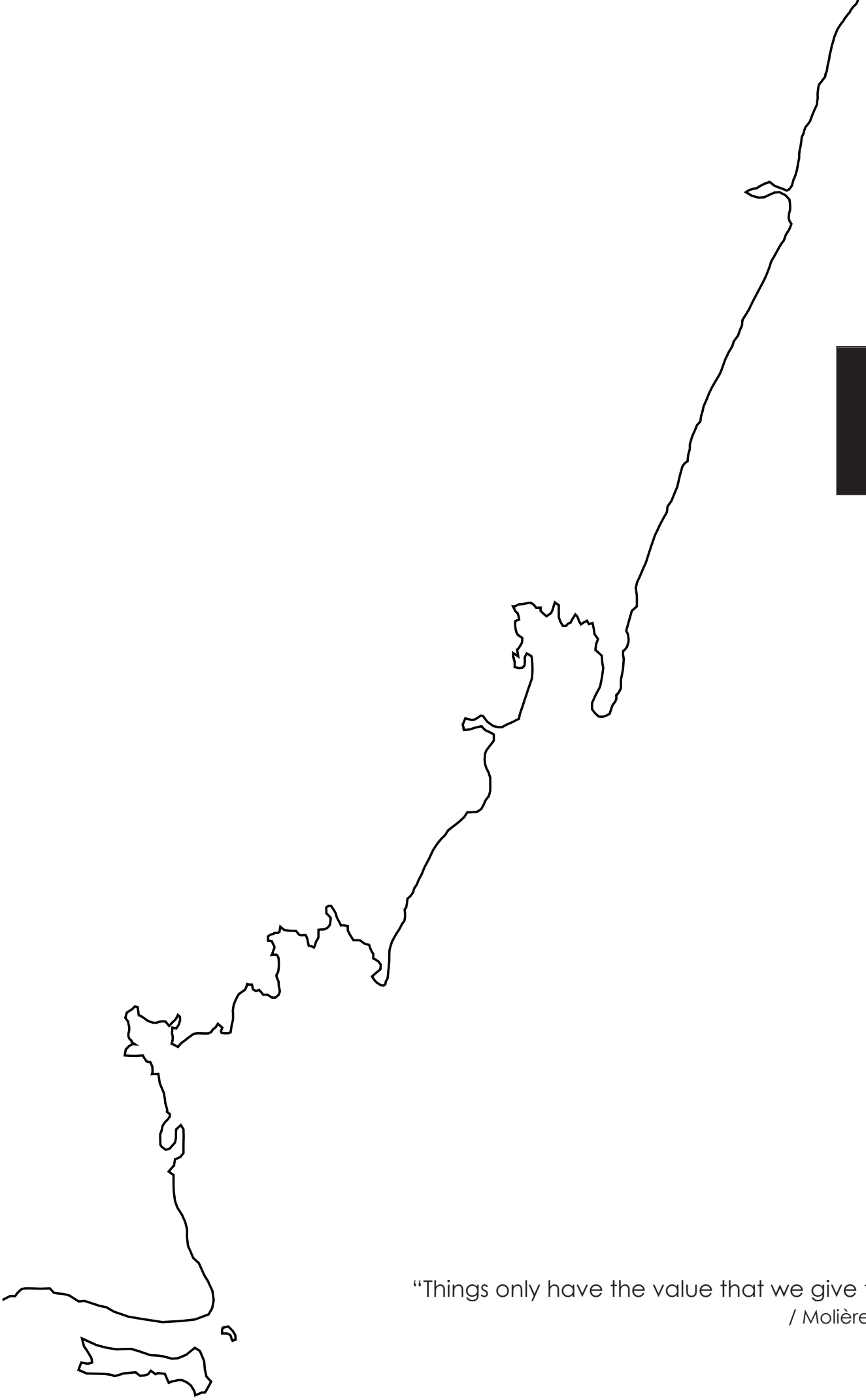
Vance, D.J., Haywood, M.D.E., Heales, D.S., Kenyon, R.A., Loneragan, N.R., Pendrey, R.C., 1996. How far do prawns and fish move into mangroves? Distribution of juvenile banana prawns *Penaeus merguiensis* and fish in a tropical mangrove forest in northern Australia. Marine Ecology Progress Series 131, 115–124.

Vance, D.J., 1992. Activity patterns of juvenile penaeid prawns in response to artificial tidal and day-night cycles: a comparison of three species. Marine Ecology Progress Series 87 (3), 201–213.

Vance, D.J., Haywood, M.D.E., Heales, D.S., Kenyon, R.A., Loneragan, N.R., 1998. Seasonal and annual variation in abundance of postlarval and juvenile banana prawns, *Penaeus merguiensis*, and environmental variation in two estuaries in tropical north-eastern Australia: a six-year study. Marine Ecology Progress Series 163, 21–36.

Vance, D.J., Haywood, M.D.E., Heales, D.S., Kenyon, R.A., Loneragan, N.R., Pendrey, R.C., 2002. Distribution of juvenile penaeid prawns in mangrove forests in a tropical Australian estuary, with particular reference to *Penaeus merguiensis*. Marine Ecology Progress Series 228, 165–177.

Warwick, R.M., Clarke, K.R., Suharsono, 1990. A statistical analysis of coral community responses to the 1982-3 El Niño in the Thousand Islands, Indonesia. Coral Reefs 8, 171–179.



II

"Things only have the value that we give them"

/ Molière 1622-1673

The Return of Ecosystem Goods and Services in Replanted Mangrove Forests – Perspectives From Two Local Communities in Kenya

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ABSTRACT

Mangroves are severely threatened ecosystems, with loss rates exceeding those of rain forests and coral reefs, stressing the need for large-scale rehabilitation programs. Not only are ecological evaluations of such planting efforts scarce, but studies of local stakeholders' perceptions and valuation of planted areas are virtually non-existent. This paper is original in assessing how resource users value natural versus planted mangroves and how they perceive plantation initiatives. Semi-structured interviews with 48 resource users from two Kenyan villages show marked mangrove dependence. Respondents identified 24 ecosystem goods, and ranked a variety of food items, traditional medicine, fuel and construction material as very important resources. Natural mangroves (11.1 ± 2.5) were rated significantly higher than plantations (4.8 ± 2.7) in terms of number ($p < 0.001$) and quality of products (mean ± S.E.), except for mangrove poles. Nine ecosystem services were acknowledged, with significant ($p < 0.001$) differences between natural (5.2 ± 1.1) and planted (4.1 ± 1.6) mangroves. Most respondents (71%) were positive to the plantations, and negative attitudes were entirely based on the perception of limited information given to the community prior to planting. Multivariate analyses show distinct patterns among user groups (based on gender, occupation and locality) with respect to recognized goods and services, knowledge of mangrove species and plantations, and attitudes towards threats, community management and existing plantations. Homogeneity of responses within defined user groups accounts for these patterns. Perspectives of local users are analyzed in relation to information from interviews with six managers and researchers responsible for existing plantations, as well as scientific studies on the return of ecosystem functions in planted mangroves of the area. Findings are discussed in the context of ecological knowledge, learning within social groups, village setting and history, and primary economic activity. We conclude that communication of plantation goals may be fundamental to project success and sustainability, and that community participation should take into account the heterogeneous nature of stakeholder groups, in terms of perceptions and valuations of ecosystem goods and services, to avoid conflicts on future plantation use.

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1. INTRODUCTION

Mangrove ecosystems have experienced widespread deforestation and degradation throughout the tropics and subtropics. The exact losses are difficult, if not impossible, to determine due to inaccurate recent surveys or historical estimates not based on empirical measurements (Spalding et al. 1997, Valiela et al. 2001). Valiela et al. (2001) calculated that at least 35% of the world's mangrove area has been lost since the early 1980s, corresponding to an annual loss rate of 2.1%. This exceeds the loss rates for tropical rain forests and coral reefs, two widely acknowledged threatened environments (Valiela et al. 2001). Major reasons for mangrove destruction are urban development, diversion of freshwater flows, over harvesting of fuel wood and timber as well as conversion into development activities like aquaculture, agriculture, mining and salt extraction (Saenger et al. 1983, Valiela 2001, Alongi 2002). The establishment of shrimp ponds has been the main cause behind mangrove loss in many countries, and in some locations it has accounted for all of the conversion (e.g. Primavera 1998, Ronnback 2001). Kenya has lost about 20% of its mangrove forests, mainly due to the conversion into ponds for salt extraction (Abuodha & Kairo 2001). The remaining forests are in many locations also degraded by unsustainable extraction of fuel wood and timber.

In recent years there has been an increasing awareness of the fact that mangroves provide many valuable functions free of charge. They generate a wide range of ecosystem services like protection against floods and storms, reduction of riverbank and coastal erosion, water quality maintenance, etc. (e.g. Saenger et al. 1983, Ewel et al. 1998, Moberg & Ronnback 2003). These services are key features that sustain economic activities in coastal areas in many countries. In addition to the multiple services, a variety of natural resources from mangroves are vital to subsistence economies and provide a commercial base to local and national economies (e.g. Hamilton & Snedaker 1984, Bandaranayake 1998, Ronnback 1999).

A number of countries have initiated mangrove rehabilitation programs in degraded mangrove systems or abandoned shrimp ponds (Field 1996, 1998, Spalding et al. 1997, Stevenson 1997,). More than 100 countries harbor mangroves, but extensive replanting of these forests (areas > 100 km^2) has been achieved only in Bangladesh, India, Indonesia, the Philippines, Thailand and Vietnam (Field 1998). The worldwide coverage of rehabilitated

mangroves is some 3000 km^2 (Field 1998), which is less than 2% of all the world's mangrove habitats (Spalding et al. 1997). Annual loss rate of mangroves thus exceeds the total rehabilitated area up to date, stressing the urgent need to launch more extensive rehabilitation programs.

The success of mangrove rehabilitation can be evaluated based on three major criteria (Field 1998). First, effectiveness of planting, i.e., to what extent the objectives of the rehabilitation program are met. Second, rehabilitation efficiency in terms of labor, resources, etc. Third, the recruitment rate of associated flora and fauna, i.e., measuring the recovery of ecosystem structure and function. The first two criteria are sometimes assessed, whereas the recruitment aspect rarely receives attention in mangrove rehabilitation (Field 1998, Crona & Ronnback 2005, Crona et al. 2006). Effectiveness of rehabilitation is best measured against the original objectives, which in most cases revolve around three main goals: (i) conservation of natural system and landscaping; (ii) sustainable production of natural resources; and (iii) protection of coastal areas (Field 1998, 1999). The most common objective of most mangrove rehabilitation programs is silviculture, followed by coastal protection (Field 1996, 1998, Alongi 2002). Sustainable production of natural resources as a rehabilitation goal thus focuses on commercial extraction of forest products, especially timber and sometimes charcoal. The wide variety and immense importance of subsistence and small-scale commercial products as well as services apart from coastal protection is seldom acknowledged.

The success of mangrove rehabilitation programs in populated areas, especially in developing countries, will largely depend on the inclusion of local communities as an integral component of the mangrove system. Diverging views on plantation goals and ensuing conflicts may otherwise hamper the process (Field 1998). Walters (2000, 2003) studied the initiatives of local communities to plant (monoculture *Rhizophora stylosa*) and manage mangroves for coastal protection, establishment of tenure claims and access to construction material. However, to our knowledge there are no studies (in peer-reviewed journals) including local users' perspectives, whether prior to, during or after the implementation of rehabilitation program supported by governments or non-governmental organizations. Nor has there been any scientific assessment of how resource users value natural and planted mangroves with regards to provision of ecosystem goods and services. These are serious shortcomings, and it could be questioned whether the success of most

rehabilitation programs in developing countries can at all be measured without the inclusion of these aspects. Serious concern for future management and sustainable use of rehabilitated sites may also present themselves if the interests and opinions of locals have not been taken into account.

Against the backdrop of this critique the study set out to evaluate how local communities perceive and value ecosystem goods and services associated with both natural and replanted mangroves in southern Kenya. Resource users in two coastal communities were interviewed to (i) assess the local dependence on mangrove ecosystem goods and services and (ii) describe the views and attitudes of local communities with respect to threats, regulations, plantations and community management of mangroves. The results are analyzed and discussed in the context of local communities' ecological knowledge, mangrove dependence and attitude to natural versus planted mangroves, as well as the potential for community management. Distinguishing patterns of resource valuation among users groups based on occupation, gender and village background are also outlined. Through interviews with managers and researchers responsible for mangrove management and existing plantations we also outline the institutional framework surrounding management of mangrove forests and plantations to provide a historical background and context against which community perceptions can be analyzed.

2. METHODOLOGY

2.1 Study area

The area of focus in this study is located approximately 50 km south of Mombasa in Kenya, and comprises two rural communities – Gazi and Makongeni (Fig. 1). The majority of inhabitants in both villages are involved in subsistence livelihoods, although these differ such that close to 90% of the men in Gazi village are involved in fisheries, while a large portion of the households in Makongeni are fulltime farmers. This is partly because Gazi is located closer to the sea, while Makongeni lies in the vicinity of more arable land. Women in both communities earn most of their income from either weaving *makuti* (roof thatches made from coconut fronds) or mats, or from collection of firewood, mollusks and crustaceans, and from preparing and selling food. Gazi has approximately 1000 inhabitants

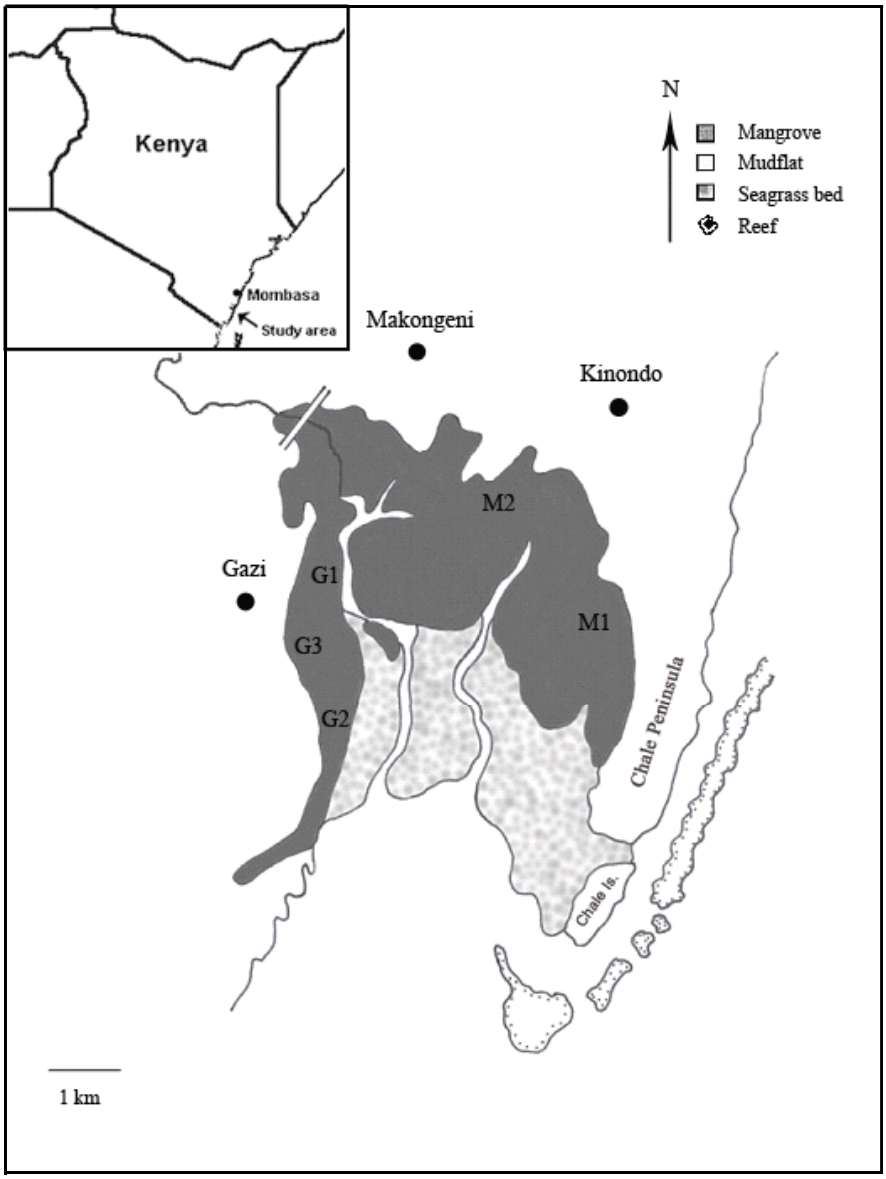

Figure 1. Map of the study area, indicating location on the southern Kenyan coast (4°25'S and 39°50'E), approximately 50 km south of Mombasa. The picture shows the coastal seascape in focus with the respective distribution of mangroves, mudflats, seagrass beds and reefs. Plantations and their respective location in relation to villages and natural mangroves are also indicated.

while Makongeni hosts approximately 400. The history of the villages differs slightly. Gazi dates back to colonial times, while Makongeni was founded in the late 1980's when a large sugar company operating in the area closed down and former employees decided to remain and settled in the area.

2.1.1. Natural mangroves

The seascape of the area is characterized by mangroves covering approximately 5 km^2 (Mwashote and Jumba 2002) with mudflats and seagrass meadows in the shallow part of the bay. The lagoon is sheltered from intense wave impact by shallow reefs at the mouth of the bay (Fig. 1). Mangrove species occurring in Kenya are *Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza, Avicennia marina, Sonneratia alba, Lumnitzera racemosa, Xylocarpus granatum, X. moluccensis, Heritiera littoralis* and *Pemphis acidula*. Of these, the latter three are very rare or non-existent in the study area (Kairo & Dahdouh-Guebas 2004).

The mangroves in Kenya have been legally declared as government reserve forest since proclamation NO 44, in 1932, and later by legal notice in 1964 (Kairo and Kivyatu 2000). The chief conservator of forests (CCF) is the highest responsible authority for forest in Kenya, followed by the provincial forest officer (PFO) and a district forest officer (DFO) under whose charge a number of forest guards and extension staff operate and patrol the area. At the time of the study there was currently only one forest guard working in the area.

Historically the main threat to mangroves has been excessive timber extraction and to some degree extraction of fuel wood. In response to this several bans on mangrove related product exports have been issued over the years. In 1997 the first ban on national exploitation of any type of mangrove forest product was issued and has since been enforced, with periodical local exceptions, to present day.

2.1.2. Plantations

The first experimental mangrove plantations in the area were started in the early 1990s. The main objective then was to test the suitability of different species in relation to inundation. After three years of monitoring, larger plantations were established in 1994. The main objective with these plantations was to restore areas degraded by timber extraction in the 1970s, which had shown no signs of natural regeneration. As the objective was to restore the area only species occurring naturally were planted. These included *Rhizophora mucronata*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, *Avicennia marina* and *Sonneratia alba*. The planting project was conducted through Kenya Marine and Fisheries Research Institute (KMFRI) with the help of external funding.

For the purpose of this study five plantations were included in the analysis. Three of them are located close to Gazi village (G1, G2, G3), and two located closer to Makongeni (M1, M2) (Fig. 1). G1 is a monostand of *Sonneratia alba* (0.5 ha) and G2 is an integrated plantation of *S. alba* where seedlings were planted in degraded forest (3 ha) (Kairo 1995). Both these plantations were approximately 10 years old at the time of data collection. The G3 plantation is only 4 years old and is a monostand of *Ceriops tagal* (0.5 ha). M1 is a monostand of *Rhizophora mucronata* and the largest of all the plantations (6.7 ha). It is approximately the same age as G1 and G2. M2 consists of *C. tagal* and *R. mucronata*. It is smaller than M1 and planted in 1998. M1 differs from the other plantations, as it is located notably further from any of the villages. Further data on the plantations can be found in Kairo (1995).

2.2. Interviews

During April-June of 2004, 48 semi-structured interviews were conducted with resource users in the two target communities, corresponding to approximately 3% and 5% of the entire population in Gazi and Makongeni, respectively. An inventory was made of all the people in each village who use the mangrove regularly and respondents were randomly selected from this list. Mangrove use was defined as any activity closely related to the mangrove habitat, such as fishing and harvesting of forest products.

In each village at least ten men and ten women were interviewed and grouped as follows. Gazi – women (n=10 respondents) and men (n=18). Men were further sub-divided into fishermen (n=10), pole cutters (n=5) and other occupations (n=3). Makongeni – women (n=10) and men (n=10), also subdivided into pole cutters (n=7) and other occupations (n=3). The sub-division into fishermen and pole cutters was based on the respondents' primary income source. At the time of study, some pole cutters had other income sources due to the ban (see above), but still identified themselves as pole cutters. The age of the respondents ranged from 25 to 70 years, and no major difference in age structure existed between user groups (39-49 years of average age).

Interviews with villagers were conducted in Kiswahili, in the home of the respondents. The questionnaire was divided into a qualitative and a quantitative section. Questions of the qualitative sections were partitioned under four themes: (i) ecological knowledge about the mangrove forest and related threats; (ii) knowledge of the plantations and local community

participation in the planting projects; (iii) goods and services of natural mangroves as well as plantations; and (iv) regulations for mangrove forest use and extraction. In the quantitative section, mangrove goods and services were classified into 22 and 7 different categories, respectively, based on personal observations and previous documentations of mangrove importance (e.g. Saenger et al. 1983, Hamilton & Snedaker 1984, Ronnback 1999). Respondents were asked if they, or someone else, use/enjoy (or have used/enjoyed) the good/service and if the planted mangroves provide this resource. The relative importance of each type of good and service was also inquired about (rated on a three point scale: low importance, important and very important). Acknowledgement of ecosystem services was followed up by questions about the supportive function(s) of mangroves supplying these to assess the ecological knowledge behind the reasoning.

Apart from resource users, two licensees, a forest guard, two researchers and the Kwale district forest officer (DFO) were interviewed to better understand the institutional framework around the management of the mangrove forests and plantations, as well as to investigate future possibilities of community management. Interviews with the researchers and DFO were conducted in English and took place in their office.

2.3. Data analysis

The transcripts from the 48 interviews with resource users and six interviews with managers and researchers resulted in more than 400 pages of text. Each individual interview transcript was incorporated into an extensive quantitative matrix. The total number of identified ecosystem goods and services, and the relative proportion (%) of resource users acknowledging their provision from natural and planted mangroves were estimated. Ecosystem goods were grouped into commodities (food, fuel, construction material, etc.) and services grouped into functions (regulating, reproduction and cultural) (e.g. de Groot et al. 2002, Ronnback et al. forthcoming). The relative importance of products and services was estimated according to the ranking given by the majority of users. The qualitative section of the questionnaire was analyzed to assess ecological knowledge and perspectives on mangrove species, number of plantations, threats, regulations and community management as well as the relative value of plantations in comparison to natural mangroves.

Both qualitative and quantitative answers given by respondents were evaluated with the help of multivariate analysis to distinguish group specific features and differences. Two Principal Component Analyses (PCA) were performed for this purpose to explore patterns among respondents based on occupation, gender and village membership. Multivariate analysis was conducted using Canoco 4.5.

T-tests for dependent samples were performed to compare the number of goods and services originating from natural as well as planted mangroves, according to respondents. Prior to t-tests, the distribution of paired differences was checked for normality. Univariate statistics were performed using Statistica 7.0.

3. RESULTS

The most common definitions of mangroves among respondents was "*trees that grow in the sea*", followed by "*good building material*". Knowledge of mangrove species in the area was good, and as many as 77% recognized four to six species of trees. Most respondents thought mangroves were beautiful: "*Of course, they are beautiful. If possible they should be planted in the village, but it is impossible since they need seawater.*"

3.1 Mangrove ecosystem goods

Local resource users acknowledged 24 different types of mangrove goods (Table 1). Some goods (mammals, fur, skin, fruit, cooking oil, alcohol, wax and fish poison) were not recognized, whereas some respondents suggested additional goods (fishing bait, fishing floats, lime and insect control) to the ones specified in the questionnaire. Most resources (16 out of 24) could be classified as major goods (defined here as goods acknowledged by at least 20% of users and ranked as important or very important). Products of significant importance and recognized by all users included fish, shrimp, firewood and poles (Table 1). Honey, boat building material, furniture and traditional medicine were other very important resources widely acknowledged. One respondent stated that without furniture from mangroves "*we would not have any place to sleep, no beds*". Traditional medicine was derived from all tree components (leaves, fruits, bark and roots) and used for stomach problems, fever, removal of hookworms and fly eggs, as well as warding off evil spirits.

Table 1. Ecosystem goods provided (% of all respondents) by natural and planted mangroves according to local resource users in Gazi Bay, Kenya (n=48). Relative importance: * low importance, ** important, *** very important

	Natural mangroves	Planted mangroves	Relative importance
FOOD			
Fish	100	32	***
Shrimps	100	40	***
Honey	90	15	***
Molluscs	85	42	**
Birds and eggs	29	23	*
Tea	2	2	*
Vinegar	2	0	*
FUEL			
Fire wood	100	38	***
Charcoal	19	2	***
CONSTRUCTION MATERIAL			
Poles, beams, panelling	100	63	***
Boat building	83	33	***
Timber	33	4	***
HOUSEHOLD ITEMS			
Dye for cloth and nets	88	65	**
Furniture	65	25	***
Glue	19	15	*
Tannins for net preservation	4	4	***
OTHER GOODS			
Traditional medicine	60	19	***
Fodder	56	31	**
Fishing bait (worms) [1]	33	21	**
Raw material for handicraft	21	8	**
Fishing floats [1]	10	8	***
Fertilisers	8	6	**
Lime from mollusc shell [1]	2	0	**
Insect control [1]	2	0	**

[1] mangrove support probably underestimated as resource not specified by interviewer

Charcoal was ranked as very important, but only recognized by 19% of users, probably due to the fact that production is located in other villages. Mangrove bark is used for coloring of cloth and nets (dyes), net preservation (tannins) and glue production. Handles to the traditional colorful fan is the most common handicraft use of mangrove wood, but other items like tree carvings (from *Xylocarpus granatum*), traditional drums, cooking sticks, handles for axes and spades, shoes and earrings are also produced. Mangrove leaves (*Avicennia marina* and *Ceriops tagal*) are used as animal fodder, and mixing mangrove

leaves with sand produces fertilizers. *Sonneratia alba* roots (pneumatophores) are used as fishing floats. Vinegar (produced from honey residues), tea (*Ceriops tagal* leaves), lime from mollusk shells and leaves for insect control (flies are attracted and then stuck to *A. marina* leaves) were items of limited importance.

The number of acknowledged mangrove products per respondent differed substantially within user groups (Table 2). Fishermen identified most goods (10-17) and were the only group to acknowledge tannins, vinegar and tea. In contrast, only two pole cutters from Gazi recognized ten products or more. The ecological knowledge among women from Gazi varied markedly, and some women could only identify six goods. Men generally had a better knowledge compared to women, apart from four resources (mollusks, fodder, raw material for handicraft and fishing bait) in Gazi and two resources (mollusks and dyes) in Makongeni. The main differences between the two villages were the acknowledgement of goods such as birds/eggs, fodder and traditional medicine. No respondents in Makongeni recognized birds or eggs as a mangrove resource, compared to 50% in Gazi. The majority (75%) of users in Gazi acknowledged fodder compared to less than one third in Makongeni. The opposite applied for traditional medicine, recognized by 80% and less than 50% in Makongeni and Gazi, respectively.

Table 2. Relative perspectives on mangrove goods and services, plantations, threats and management among local communities in Gazi Bay, Kenya. Male respondents are sub-divided into fishers and pole cutters.

	GAZI				**MAKONGENI**			**TOTAL**
	WOMEN	**MEN**			**WOMEN**	**MEN**		
		total	*fishers*	*pole cutters*		*total*	*pole cutters*	
	n=10	**n=18**	n=10	n=5	**n=10**	**n=10**	n=7	**n=48**
NATURAL MANGROVES								
Mangrove products	6-15	7-17	10-17	7-13	7-14	8-13	10-13	6-17
Mangrove services	2-7	4-8	4-8	3-6	5	5-6	5-6	2-8
PLANTED MANGROVES								
Mangrove plantations	1.8	2.4	2.4	2.4	1.6	1.4	1.4	1.9
Aware of planted species	40%	78%	70%	100%	100%	100%	100%	79%
Mangrove products	1-10	2-10	2-10	2-6	2-6	2-10	2-10	1-10
Mangrove services	0-5	3-7	3-7	2-6	3-5	4-6	4-6	0-7
Natural mangrove has highest value	100%	89%	90%	80%	70%	60%	71%	81%
Positive towards plantations	80%	89%	90%	80%	60%	40%	29%	71%
MANAGEMENT								
Mangroves are threatened	60%	83%	90%	80%	90%	100%	100%	83%
Regulations needed	50%	89%	80%	100%	100%	100%	100%	85%
Positive to community management	20%	44%	50%	20%	40%	90%	86%	48%

Table 3. Ecosystem services provided (% of all respondents) by natural and planted mangroves according to local resource users in Gazi Bay, Kenya (n=48). Relative importance: * low importance, ** important, *** very important

	Natural mangroves	Planted mangroves	Relative importance
REGULATING FUNCTIONS			
Storm and flood protection	90	79	***
Erosion control	83	73	***
Water quality maintenance	8	4	**
Climate regulation [1]	8	6	***
REPRODUCTION FUNCTIONS			
Habitat and nursery ground	100	67	***
Link to other marine systems	94	67	***
CULTURAL FUNCTIONS			
Cultural and religious values	25	10	**
Recreation and tourism	98	75	***
Information function [1, 2]	15	10	

[1] mangrove support probably underestimated as service not specified by interviewer
[2] relative importance not asked

3.2 Mangrove ecosystem services

In total, local resource users acknowledged nine different types of mangrove ecosystem services (Table 3). Protection against storms, floods and erosion as well as reproductive functions and recreational values were identified by a vast majority of users, and ranked as very important services. Storm and flood protection were explained by respondents as mangroves providing a mechanical wall offering wind protection as well as preventing high tides from reaching the village. Erosion control was explained by tree canopies reducing the movement of heavy rains and mangrove roots holding the soil firmly, preventing erosion by rain, waves and high tides. Less than 10% of the respondents acknowledged that mangroves can maintain water quality if exposed to sewage. Only two respondents mentioned the ability of mangroves to clean water, and two others mentioned nutrients in the sewage as potential fish food or mangrove fertilizers. Some respondents mentioned the ecosystem service of local climate regulation, which was not specified in the questionnaire. The underlying explanation for this was that mangroves attract rain and protect from cold winds.

A variety of mechanisms and mental models were used by respondents to explain the reproduction functions of mangroves. The use of mangrove habitat as nursery, breeding and feeding ground was based on the provision of food, shelter/protection, shade and cool water. Mangroves were often referred to as a "*good house*" for fish, shrimps, crabs, mollusks and birds. The majority of resource users also exhibited some knowledge on the biophysical links between mangroves and other ecosystems in the seascape, i.e., seagrasses and coral reefs. Fish were recognized as migrating substantially between these coastal systems, following daily tidal dynamics or seasonal life history migrations, illustrated by comments such as: "*… coral reef fish come to feed and lay eggs [in the mangroves] and then return. Eggs hatch, then the fish go to the corals*."

Religious values are associated with sacred areas (*kayas*) holding "*shrines in old mangroves*". These *kayas* are visited to cure and reduce susceptibility to diseases and evil spirits. All respondents acknowledged aesthetic values of mangroves by always referring to the system as beautiful, or even very beautiful. Recreational values for tourists were also evident and explained by the attraction of fresh air, good breeze, good shadow and shelter as well as opportunities to photograph birds. Some respondents touched upon the information function of mangroves when describing the reasons behind tourists visiting the area: "*tourists don't know about mangroves*", "*… [tourists] have no mangroves in their country*" and "*…[tourists] come to learn*". This information function can also be viewed as an ecosystem service. Most respondents stated that the revenues from tourism go primarily to people outside the villages. However, 50% of Makongeni men expressed personal benefits working as tourist guides, compared to only 17% of people from Gazi recognizing this as a potential income to the village.

Only two respondents could identify any negative aspect of having mangroves close to the village. Disservices mentioned included problems with mosquitoes and wild animals such as baboons.

The general pattern among resource users shows that fishermen acknowledged more services than pole cutters, and men more than women (Table 2). Answers also differ substantially between villages. Services such as water quality maintenance, climate regulation and information functions were almost exclusively recognized by Gazi respondents. The appreciation of religious values was also more pronounced in Gazi.

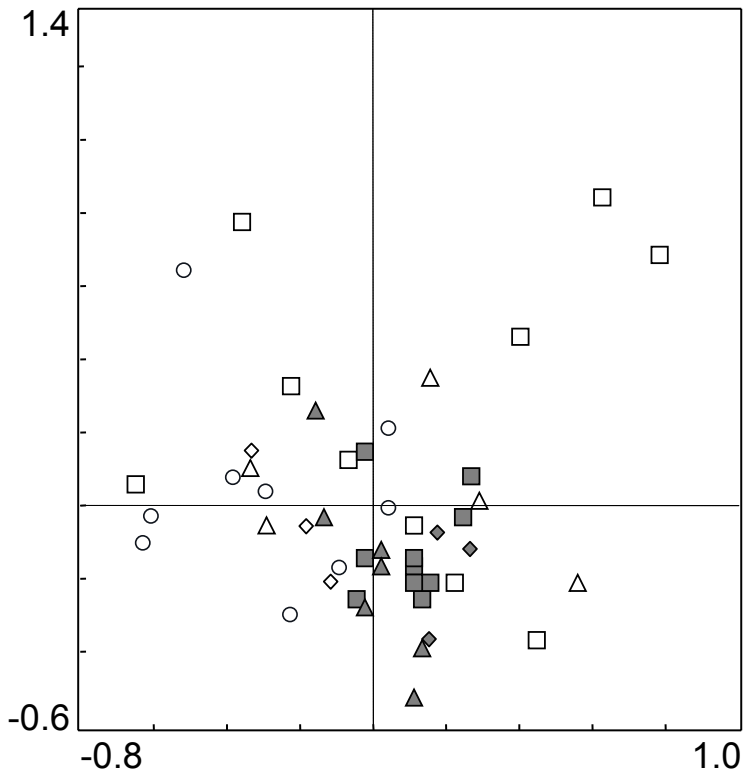

Figure 2. Principal Component Analysis (PCA) showing the relative distribution of respondents with respect to their answers regarding views on goods and services provided by natural mangroves (n=47). Gazi men (fishers) = open circles, Gazi men (pole cutters) = open triangles, Gazi men (other occupations) = open diamonds, Gazi women = open squares, Makongeni men (pole cutters) = filled triangles, Makongeni men (others) = filled diamonds, Makongeni women = filled squares. One marked outlier (Gazi male fisher recognizing tea and vinegar products) was excluded. Cumulative variance accounted for by axis 1 (9.8) and axis 2 (9.0) is 18.8%.

Everybody from Makongeni recognized storm and flood protection as well as erosion control, compared to only 60% of the women from Gazi. The detail in recognition of goods and services was more heterogeneous among respondents in Gazi (Fig. 2), and some women and pole cutters could, for example, only identify two to three services. The homogeneity among Makongeni respondents, with respect to this is illustrated by the tighter clustering of Makongeni respondents in Fig. 2, compared with those from Gazi. This is partly due to the fact that all Makongeni users acknowledged a narrower range of five to six services, while Gazi users listed two to eight services (Table 2).

There is a clear distinction between the two villages concerning the historical change in mangrove importance. Most users from Makongeni (90%) argue that mangroves are more important today based on an increased population more dependent on mangrove resources. In the past they relied on terrestrial forest for house constructing material, but those forests

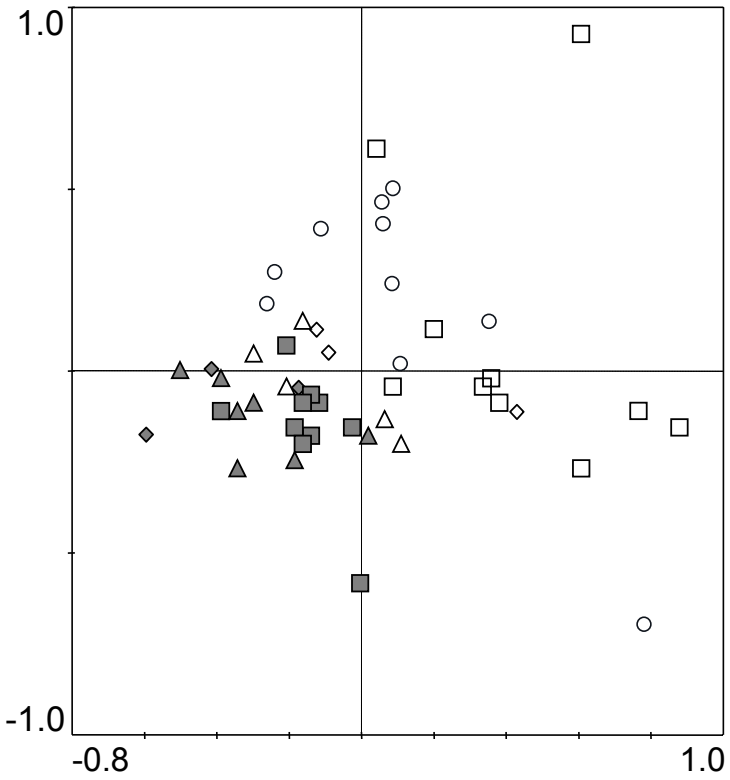

Figure 3. Principal Component Analysis (PCA) showing the relative distribution of respondents with respect to their answers regarding views on mangrove management, plantation initiatives and goods and services provided by mangrove plantations (n=48). Gazi men (fishers) = open circles, Gazi men (pole cutters) = open triangles, Gazi men (other occupations) = open diamonds, Gazi women = open squares, Makongeni men (pole cutters) = filled triangles, Makongeni men (others) = filled diamonds, Makongeni women = filled squares. Cumulative variance accounted for by axis 1 (11.4) and axis 2 (7.6) is 19.0%.

are now gone, so they rely increasingly on mangroves. Another reason given is that they are now more educated about mangrove planting and the potential use of this in the area. In Gazi, more than 70% of interviewed users are of the opinion that there is no historical change in mangrove importance or that mangroves were more important in the past. The perceived reduction in importance of mangroves is motivated by the fact that more people are better off today and can thus afford to buy manufactured substitutes for some mangrove resources.

3.3 Natural vs. planted mangroves

Most respondents could identify two out of five plantations (Table 2). Everyone was aware of at least one plantation, but no one knew more than three. Furthermore, most respondents only knew about the plantations in the vicinity of their village, and consequently Gazi villagers identified more plantations. All men and women from Makongeni knew the name

of planted mangrove species in at least one of the plantations, while only pole cutters from Gazi shared this level of knowledge. The closer resemblance between Gazi pole cutters and respondents from Makongeni in many respects is seen by their overlapping distribution in Fig. 2 and 3. In Gazi men had better knowledge of the number of plantations and planted species than women.

Overall, the majority of respondents (81%) thought natural mangroves were more valuable than the plantations (Table 2). However, more than one third of Makongeni respondents argued that the plantations were more valuable. The main reason given was that the plantations will produce more poles of good quality, out-weighting the fact that natural mangroves produce more products.

The number of products that the plantations (4.8 ± 2.7) could provide was significantly ($p < 0.001$) lower compared to natural mangroves (11.1 ± 2.5) (mean values ± s.d., n=48) when compared across all groups of respondents. One third of respondents only recognized one or two products supported by the plantations. Poles and bark for dye production were the only resources acknowledged as produced by plantations by more than 50% of interviewed users (Table 1). Only 15-40% of respondents thought plantations could provide very important resources such as fish, shrimp, honey, firewood and traditional medicine. Honey production was said to be strongly associated with the natural forest, explained through the preference of bees for old, hollow trees to build their hives. Fishermen generally acknowledged more goods from the plantations than pole cutters, and men more than women. Men from Makongeni were most positive to the ability of plantations to support the same resources they identified from the natural forest.

The number of services that the plantations (4.1 ± 1.6) could provide was also significantly ($p < 0.001$) lower compared to natural mangroves (5.2 ± 1.1) (mean values ± s.d., n=48). Respondents from Makongeni were most positive to the potential of plantations to provide services and all thought the plantations attract tourist and provide storm, flood and erosion protection, compared to only 40-78% of Gazi respondents. The latter spoke of reduced wind protection provided by plantations due to less developed forest canopies and sacred areas were mainly associated with old and mature mangroves. The plantations' limited support to reproduction functions negatively affected fisheries catch in terms of productivity as well as quality (species and size of individuals). Respondents explained this

by saying that the environment is better in the natural mangrove, which offers more food, better shelter, muddier substrate and encompass holes and channels that always hold water, even at low tide.

The majority of users (92%) thought the plantations would be more beneficial in the future. Many argued that the plantations are still too young to have any old and dry branches to collect for firewood. The trees are also too young and small to support the production of charcoal, timber and boat building material. One fifth of the respondents even believed that the plantations would be more beneficial than the natural mangroves in the future, based primarily on the presence of large poles of very good quality. They also argued that fish and shellfish would return to the plantations in the future. Most respondents expressing this view come from Makongeni village.

3.4 Attitudes towards the plantations, regulations and community management

Overall, most people interviewed (71%) had a positive attitude towards the plantations (Table 2), based on the possibility of harvesting more products from them in the future. In spite of this, half of the Makongeni villagers were negative to the plantations. Although positive to planting of mangroves in general, their view was that the current plantations were initiated without informing them beforehand. Most argued that they were not informed (65%) and some could not remember (10%). In Gazi, more than 60% of the users verified direct sharing of information beforehand.

Interviewed scientists involved in the initiation and implementation of the planting programs maintain that the goal was to restore the type of forest that had originally grown in the degraded areas. Although the ultimate objective of this was the continued provision of goods and services to the community the plots are too small in size to support any large-scale extraction of wood products and thus only ecosystem services and non-forest products are available to the community at present. The planted areas are viewed as strictly research plots, a status reinforced by the fact that they are planted on government land and considered by the Forest Department as permanent sample plots for investigation. According to scientists involved, information meetings were held with the village (Gazi) before planting, focusing on the ecological aspects of conservation and reforestation, and the village gave their approval. However, the concept of indirect uses, i.e. ecosystem services, was not introduced until ten years later during a national awareness program.

There is a unanimous view among researchers and officials interviewed that the local community is well aware of the purpose of the plantations and the necessity of reforestation. Interviews with local residents, however, show diverging perceptions of the information given to, and involvement of, the community in the replanting. These perceptions also differ between villages, as seen above.

Asked about their views on the choice of species, one third of respondents argued that they would not have made the plantations any different. However, 25% stated that they would have planted species more valuable as building material or firewood in the plantations they knew, and 15% would have mixed many species in the plantations instead of having monocultures.

Most users (83%) recognized that mangroves in the area could be threatened, although the majority of women in Gazi had no opinion (Table 2). Unsustainable extraction of forest resources (timber, poles, firewood, etc.) by locals and a calcium factory in the 1970s and 1980s have historically caused deforestation, according to respondents. More than one third of interviewed users had no suggestion on how to combat threats, whereas others called for protection of the mangroves (31%), closure of cutting (27%) or replanting of mangroves once cut (4%). When asked directly about existing regulations, all respondents were aware of the ban on cutting mangroves for firewood or construction material. With the exception of Gazi women, almost all resource users acknowledged the need for regulating the extraction of forest products (Table 3). However, most users were highly critical to the current ban and suggested alternative regulations. Pole cutters experienced major income losses, and many other users complained about the lack of good quality firewood and the inability to build or repair their houses. The majority (73%) emphasized that the ban should be lifted more frequently in time as well as space (shifting of protected areas). Four out of ten Gazi fishermen argued that they had not been negatively affected by the ban, and consequently had no suggestion for management alternatives.

Men were generally more positive to community management than women (Table 2). Makongeni men were especially positive and wanted to plant mangroves in the future. They suggested establishing a committee and setting up their own regulations, although some called for government support concerning guards to avoid kinship problems. Only one third of respondents from Gazi, mainly men, were positive to community management.

The negative views were primarily based on concerns regarding the inability of the community to control corruption and disrespect of set regulations, which could lead to conflicts in the village.

Interviewed resource users from Makongeni were very homogeneous in their attitude to threats, mangrove management, plantation initiatives and ecosystem goods and services provided by mangrove plantations, as seen in Fig. 3. The attitudes among Gazi respondents were more heterogeneous, especially among women, and this is reflected in the scattered pattern of these respondents in Fig. 3.

4. DISCUSSION

4.1 Mangrove dependence and ecological knowledge

This study confirms previous interview-based studies (Dahdouh-Guebas et al. 2000, Rasolofo 1997, Kovacs 1999, Kaplowitz 2001, Glaser 2003) of the importance of mangrove life-support functions to local communities in developing countries. In Gazi Bay, a vast majority of the recognized ecosystem goods and services are of significant importance, being acknowledged by at least 20% of the respondents and ranked as very important. Most products are not marketed, rather they provide direct subsistence inputs to the household economy and therefore are not readily accounted for in cost-benefit analyses of mangroves. The failure to take these non-marketed direct use values into account has often been a major factor behind policy decisions leading to mangrove deforestation and conversion into alternative uses such as shrimp pond aquaculture (e.g. Barbier 1994, Ronnback 1999). Furthermore, manufactured substitutes such as concrete blocks, instead of mangrove construction material, were usually viewed by respondents in this study as very expensive and not affordable. The loss of terrestrial forest resources in the surrounding areas has further increased the dependence of local communities on natural capital from the mangroves.

In this study many respondents testified to a general importance of mangroves and the majority recognized most of the mangrove tree species existing in the area. Twenty-four different types of ecosystem goods and nine services were acknowledged, including the identification of three goods as well as three services not specified in the questionnaire.

Many respondents also showed a fairly detailed understanding of the mangrove ecosystem functions supporting these services, for example, the role of mangroves in supporting migratory fish species. This is also supported by ecological studies in the area showing fish communities in natural and planted *Sonneratia alba* to be dominated (65%) by species associated to coral reef systems as adults (Crona & Ronnback forthcoming).

It has been shown that learning and cognitive development is largely influenced by the cultural context in which a person lives (Rogoff 2003). In this sense learning is the process of shaping understanding, perception, thinking, problem solving, planning, etc. together with other people, building on the cultural practices and traditions of communities (Rogoff 2003). Close social relations thus have a strong influence on a person's ideas, attitudes and perceptions (Homans 1950) and can be expected to determine these in such a way that groups of peers or co-workers exhibit similar views (Cross 2001, Reagans & McEvily 2003, Crona & Bodin 2006). Furthermore, in settings where experiential learning takes precedence over formal education, such as extraction of natural resources, knowledge is often unevenly distributed among groups depending on extraction methods as well as subject to memory loss (Neis 1999, Crona 2006). Homogeneity in terms of perceived ecosystem values, attitudes towards plantations etc. seen in this study coincides with groups defined by occupation, gender and village membership. Such similarities may be attributed, to some extent, to the factors outlined above.

Generalizations about mangrove dependence and ecological knowledge among stakeholder groups in any community have to be done with caution. For one, knowledge is difficult to quantify and may be expressed differently depending on language, formal schooling as well as habits of thought, defined by narrative structures in turn related to culture (Rogoff 2003). However, some distinct patterns could be identified among resource users in Gazi Bay (Table 2, Fig. 2, 3). Although pole cutters had a more detailed understanding of planted species, fishermen identified more types of resources and services. For resources such as fish, shellfish, tannins, fishing floats and fish bait this is only natural as they are directly linked to fisheries activities. Women only surpassed men, in this respect, for resources that by tradition and cultural convention are only harvested by females, e.g. mollusks, fodder and bark for dye production. The level of knowledge on mangrove species, threats and goods and services in general was markedly heterogeneous among women from Gazi (Fig 2, 3), with some women exhibiting poor understanding of these

issues. A similar lack of a holistic perspective on the coastal seascape and lack of recognition of links between mangroves and other ecosystems was seen among women in a previous study in the same village (Crona 2006). Based on the arguments on learning made above, a possible explanation for this pattern is that women are, by tradition, confined to certain specific tasks (such as juvenile shrimp fishing along mangrove fringes, mollusk and firewood collection), which limits their movement in the natural system and consequently also the time spent there compared to other groups such as male fishermen and pole cutters.

Another observed pattern was the distinct difference between villages in their stated dependence on some mangrove products. The narrower range of products and services perceived by Makongeni respondents is manifested in Fig. 2 as a tighter cluster compared to the more heterogeneous sample from Gazi. One example of distinct preferences is that traditional medicine was rated as more important in Makongeni, potentially because Gazi villagers perceived themselves as generally better off, thus affording pharmaceutical drugs. Higher numbers of ecosystem goods and services were identified in Gazi, which is a larger village having a longer tradition in the area and a larger variety of extractive activities associated with the mangroves. The higher proportion of fishermen in Gazi likely influenced the number of identified goods and services. Furthermore, Gazi is located closer to the ocean compared to Makongeni and the dependence on terrestrial ecosystems is thus likely more prevalent in Makongeni. This most certainly also affects the range of goods and services perceived by Makongeni villagers as these are directly associated with the mangrove species present in the vicinity of the village. The more terrestrial location of Makongeni naturally affects the composition of the mangrove tree community, which is determined by inundation patterns. Interestingly, and in contrast to Gazi, the level of knowledge among men and women from Makongeni was quite homogeneous, especially for mangrove ecosystem services. Again, the terrestrial location of the village may play a part in this pattern as the range of activities available to resource users is linked to the range of zones and diversity of the mangrove habitat as well as the linked coastal systems. In Makongeni, pole cutting as an occupation is more common, fewer men are fishermen and the distance to frequently inundated mudflats for the collection of mollusks by women is large. These factors likely all contribute to putting a stronger focus on forest-related products and services while also streamlining the perceptions of goods and services of both genders. This is supported by the overriding importance placed by many Makongeni

respondents on high quality poles in plantations, in spite of the greater range of goods and services provided by natural mangroves.

4.2 Relative importance of replanted areas

The general pattern showed that natural mangroves were perceived as significantly more valuable than the plantations in terms of the number ($p < 0.001$) and quality of ecosystem goods provided. On an average, natural mangroves supported eleven goods compared to less than five from the plantations. Only 15-40% of interviewed users thought that the plantations could support food, fuel and medicinal resources, ranked as very important and widely acknowledged from natural mangroves (Table 1). For ecosystem services, the difference between natural and planted mangroves was also significant ($p < 0.001$), and most users expressed lower quality of the services provided by the plantations. In spite of this general pattern, more than one third of Makongeni males viewed the current plantations as more valuable compared to the natural forest and apart from explanations related to pole extraction mentioned above, many Makongeni men reported receiving personal benefits by working as tourist guides to the plantations. Furthermore, they were also positive to community management and thus associated plantations with future benefits to the community. These attitudes all separate them to some degree from Gazi respondents (Fig. 3).

Many respondents believed the plantations could serve as a habitat for fish and shellfish, although the support from natural mangrove was considered as much better in terms of fisheries production. However, Crona and Ronnback (2005, forthcoming) studied juvenile fish and shrimp assemblages and found that replanted *Sonneratia alba* mangroves in Gazi Bay harbored a significant number of commercially important species as juveniles, suggesting plantations do function as nursery habitats to some degree. These ecological results were, however, collected during high tide, while the difference in fish and shrimp abundance pointed out by the local people mainly occurred at low tide. In fact, respondents also stated that the fish swim in both environments during high tide and discrepancies can thus likely be attributed to which part of the inundation cycle is in focus. It is nonetheless important to note the low tide differences recognized by respondents as it suggest that microhabitat structure, i.e. existence of tidal pools and small channels where fish and shrimp can reside, size of mangrove roots creating habitat complexity, etc., may differ between replanted and natural areas. There is to date no extensive survey of these

parameters for all types of mangroves in the area but Crona & Ronnback (2005) found differences in habitat complexity, as measured by root density, in planted and natural sites of *S. alba* supporting respondents' claims.

The positive views of plantations among interviewed subjects are largely related to the idea that these benefits will eventually be enjoyed by local communities in the future. However, as pointed out by scientists in charge, the project was never established with the intent of large-scale pole and forest product extraction. In fact, the institutional framework surrounding the plantations makes the issue of extraction rather complicated. While the planting was initiated by individual scientists through KMFRI, the ownership, and ultimate responsibility, of the planted areas lies in the hands of the government, through the Forestry Department. Any permission to extract forest products therefore has to be released from the government. Considering the view of plantations as permanent research plots, as expressed by interviewed scientists and government representatives, it is unlikely that such extractive permits will be issued for the plantations in the near future. Such mismatches in goals and perceptions between restoration programs and local users have been seen in other areas (e.g. Wetlands International Asia-Pacific 1997 cf. Field 1998) and can be potential sources of conflict or discontent in future community collaboration initiatives.

4.3 Mangrove rehabilitation programs

There are substantial economic benefits to be made by rehabilitating mangroves. In developing countries the one-time cost of planting mangroves lies in the order of hundreds USD per hectare (Tri et al. 1998, Erftemeijer & Lewis 1999) and annual costs for maintenance and, if needed, thinning are marginal. In a Vietnamese study, Tri et al. (1998) estimated a benefit to cost ratio in the order of four to five (for a range of discount rates) by comparing mangrove rehabilitation cost with the benefits from timber, some fisheries and only one ecosystem service (avoidance of sea dike maintenance cost). The annual market value of mangrove-associated fisheries lies in the order of 3000 USD per hectare (global average) in developing countries if all ecological and bio-economic links to mangroves are accounted for (reviewed by Ronnback 1999, 2000). The annual market value for one single type of good, i.e. fisheries production, thus exceeds total rehabilitation cost once the habitat function of the rehabilitated site has been restored.

However, the success of mangrove rehabilitation programs cannot solely be measured against secured growth of planted trees nor by the return of some organisms and ecosystem functions. The spectrum of benefits enjoyed by local communities from these ecosystems is commonly much wider and more complex. Furthermore, if equity issues are to be addressed the valuation of goods and services by local users should be taken into consideration. The perspectives of local communities also provide potentially critical inputs to any evaluation of rehabilitation success as they have a daily and direct contact with the resource enabling them to monitor the status continuously over time.

It is evident from this study that resource users in Gazi Bay view natural mangroves as more valuable than plantations, especially concerning their ability to support resources other than mangrove poles. The value of the plantations will likely increase in the future, but even after ten years a perceived difference in importance is present and noteworthy. In spite of this most respondents were currently positive to the existing plantations, and some reveal having changed to this positive attitude after observing that mangroves could be successfully planted. Resource users from Makongeni were most positive in terms of the goods and services provided by the plantations and saw limited difference between the value of natural and planted mangroves, when compared to Gazi villagers. Nonetheless, at the same time, negative attitude towards the plantations were particularly pronounced among women and especially men from Makongeni; attitudes which are entirely based on their perception that very limited or no information was given to them before the plantations were started. These findings suggest that communication of goals and objectives may be crucial in creating respect and support for planting programs among local stakeholders. Although poaching does not seem to be widespread in the current plantations, primarily as a result of their limited size (stated by several government and research representatives), locally anchored consensus around natural mangroves and plantation management is likely to reduce enforcement and monitoring costs, as seen from experiences in other cases and ecosystems (Ostrom 1990). Property rights regimes, including revenue distribution and constraints imposed on local users, are naturally also of critical importance for successful management (e.g. Adger & Luttrell 2000).

From an equity perspective, community participation should constitute a central component of mangrove rehabilitation programs, and in the Kenya Forestry Master Plan (GOK 1994) this is put forth as a goal for future forestry management. However,

community involvement by no means guarantees success. In Thailand, a mangrove management and rehabilitation program with community participation experienced problems with lack of motivation among, and conflicts and inequity within, the local community, etc. (Wetlands International Asia-Pacific 1997 cf. Field 1998). Similarly to this study, the program suffered from problems of communication between local stakeholders and program officials. Communication thus appears as a fundamental issue to be addressed in future planting initiatives, but other factors surely affect success as well. Documenting the perspectives of resource users from a variety of rehabilitation programs around the world could provide essential information on such factors, which could feed into analyses of driving forces and triggering mechanisms underlying different attitudes among local communities. At the end of the day, it is the respect, interest and participation of local communities that will largely determine the future of mangrove resources worldwide, especially in developing countries where dependence on these ecosystems for livelihoods is strongest.

ACKNOWLEDGEMENTS

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5. REFERENCES

Abuodha, P.A.W. & Kairo, J.G. (2001) Human-induced stresses on mangrove swamps along the Kenyan coast. *Hydrobiologia* **458**: 255-265.

Adger, W.N. & Luttrell, C. (2000) Property rights and the utilization of wetlands. *Ecological Economics* **35**: 75-89.

Alongi, D.M. (2002) Present state and future of the world's mangrove forests. *Environmental Conservation* **29**: 331-349.

Bandaranayake, W.M. (1998) Traditional and medicinal uses of mangroves. *Mangroves and Salt Marshes* **2**: 133-148.

Barbier, E.B. (1994) Valuing environmental functions: tropical wetlands. *Land Economics* **70**: 155-173.

Crona, B.I. (2006) Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. *Ecology and Society* **11**:32, http://www.ecologyandsociety.org/vol11/iss1/art32/.

Crona, B. & Ronnback, P. (2005) Utilization of replanted mangroves as nursery ground by shrimp communities in Gazi Bay, Kenya. *Estuarine, Coastal and Shelf Science* **65**: 535-544.

Crona, B. & Ronnback, P. (forthcoming) Community structure and temporal variability of juvenile fish assemblages in natural and replanted mangroves, *Sonneratia alba* Sm., of Gazi Bay, Kenya. in revision

Crona, B. I. & Ö. Bodin (2006). What you know is who you know? Patterns of communication as prerequisites for co-management. *Ecology and Society (In press)*.

Crona, B., Holmgren, S. & Ronnback P. (2006) Re-establishment of epibiotic communities in reforested mangroves of Gazi Bay, Kenya. *Wetlands Ecology and Management (In press).*

Cross, R., Borgatti, S. P. & Parker, A. (2001). Beyond answers: Dimensions of the advice network. *Social Networks* **23**(3): 215-235.

Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G. & Koedam, N. (2000) Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Economic Botany* **54**: 513-527.

Erftemeijer, P.L.A. & Lewis, III, R.R. (2000) Planting mangroves on intertidal mudflats: habitat restoration or habitat conversion? Paper presented at the ECOTONE-VIII Seminar "*Enhancing Coastal Ecosystem Restoration for the 21st Century*", Ranong & Phuket, 23-28 May 1999.

Ewel, K.C., Twilley, R.R. & Ong, J.E. (1998) Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters* **7**: 83-94.

Field, C.D. (ed.). (1996) *Restoration of Mangrove Ecosystems*. International Society for Mangrove Ecosystems, Okinawa, Japan, 250 pp.

Field, C.D. (1998) Rehabilitation of mangrove ecosystems: an overview. *Marine Pollution Bulletin* **37**: 382-392.

Field, C.D. (1999) Mangrove rehabilitation: choice and necessity. *Hydrobiologia* **413**: 47-52.

Glaser, M. (2003) Interrelations between mangrove ecosystems, local economy and social sustainability in Caeté estuary, north Brasil. *Wetlands Ecology and Management* **11**: 265-272.

de Groot, R.S., Wilson, M.A. & Boumans, R.M.J. (2002) A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* **41**: 393-408.

Hamilton, L.S. & Snedaker, S.C. (eds.). (1984) *Handbook for Mangrove Area Management*. UNEP and East West Center, Environment and Policy Institute, Honolulu, 126 pp.

Homans, G. C. (1950). *The Human Group*. Routledge & Kegan Paul Ltd, London.

Kairo, J.G. (1995) *Community participatory forestry for the rehabilitation of deforested mangrove areas of Gazi Bay, Kenya. A first approach. Final technical report.* BSP/WWF-(USA) and University of Nairobi (Botany Dept.).

Kairo, J.G. & Kivyatu, B. (2000) *Mangrove management survey within and adjacent to Kiunga National Reserve.* WWF Project KE0087.01, Technical Report. WWF EARO, Nairobi, Kenya/ UNESCO, Nairobi, Kenya.

Kairo, J.G. & Dahdouh-Guebas, F. (in press) Republic of Kenya. In: *Principles for a Code of Conduct for the Sustainable Management of Mangrove Ecosystems : Country studies*, eds. Macintosh, D. J. & Ashton, E. C. Okinawa, Japan: International Society of Mangrove Ecosystems (ISME).

Kaplowitz, M.D. (2001) Assessing mangrove products and services at the local level: the use of focus groups and individual interviews. *Landscape and Urban Planning* **56**: 53-60.

Kovacs, J.M. (1999) Assessing mangrove use at the local scale. *Landscape and Urban Planning* **43**: 201-208.

Moberg, F. & Ronnback, P. (2003) Ecosystem services in the tropical seascape: ecosystem interactions, substituting technologies, and ecosystem restoration. *Ocean and Coastal Management* **46**: 27-46.

Mwashote, B.M. & Jumba, I.O. (2002) Quantitative aspects of inorganic nutrient fluxes in the Gazi Bay (Kenya): implications for coastal ecosystems. *Marine Pollution Bulletin* **44**: 1194-1205.

Neis, B., D. Schneider, et al. (1999). Fisheries assessment: what can be learned from interviewing resource users? *Canadian Journal of Fisheries and Aquatic Science* **56**: 1949-1963.

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, Cambridge.

Primavera, J.H. (1998) Tropical shrimp farming and its sustainability. *In: Tropical Mariculture*, S. de Silva (ed.), Academic Press, London, pp. 257-289.

Rasolofo, M.V. (1997) use of mangroves by traditional fishermen in Madagascar. *Mangroves and Salt Marshes* **1**: 243-253.

Reagans, R. & McEvily, B. (2003) Network structure and knowledge transfer: the effects of cohesion and range. *Administrative Science Quarterly* **48**: 240-267.

Rogoff, B. (2003) *The Cultural Nature of Human Development*. Oxford University Press, Oxford.

Ronnback, P. (1999) The ecological basis for the economic value of mangrove forests in seafood production. *Ecological Economics* **29**: 235-252.

Ronnback, P. (2000) Fisheries and shrimp aquaculture supported by mangroves: the ecological basis for economic valuation. Proceedings of the International Society for Mangroves (ISME) conference *"Sustainable Use of Estuaries and Mangroves: Challenges and Prospects"*, May 22-28, 2000, Recife, Brazil.

Ronnback, P. (2001) *Shrimp aquaculture – state of the art*. Swedish EIA Centre, report 1. Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden, 50 pp.

Ronnback, P., Kautsky, N., Pihl, L., Söderqvist, T., Troell, M. & Wennhage, H. (forthcoming) Ecosystem goods and services from temperate coastal habitats – identification, valuation and implications of ecosystems shifts. *Ambio (In review).*

Saenger, P., Hegerl, E.J. & Davie, J.D.S. (eds.). (1983) Global status of mangrove ecosystems. *The Environmentalist*, **3** (supplement No. 3), 88 pp.

Spalding, M., Blasco, F. & Field, C. (1997) *World Mangrove Atlas*. The International Society for Mangrove Ecosystems, Okinawa, Japan, 178 pp.

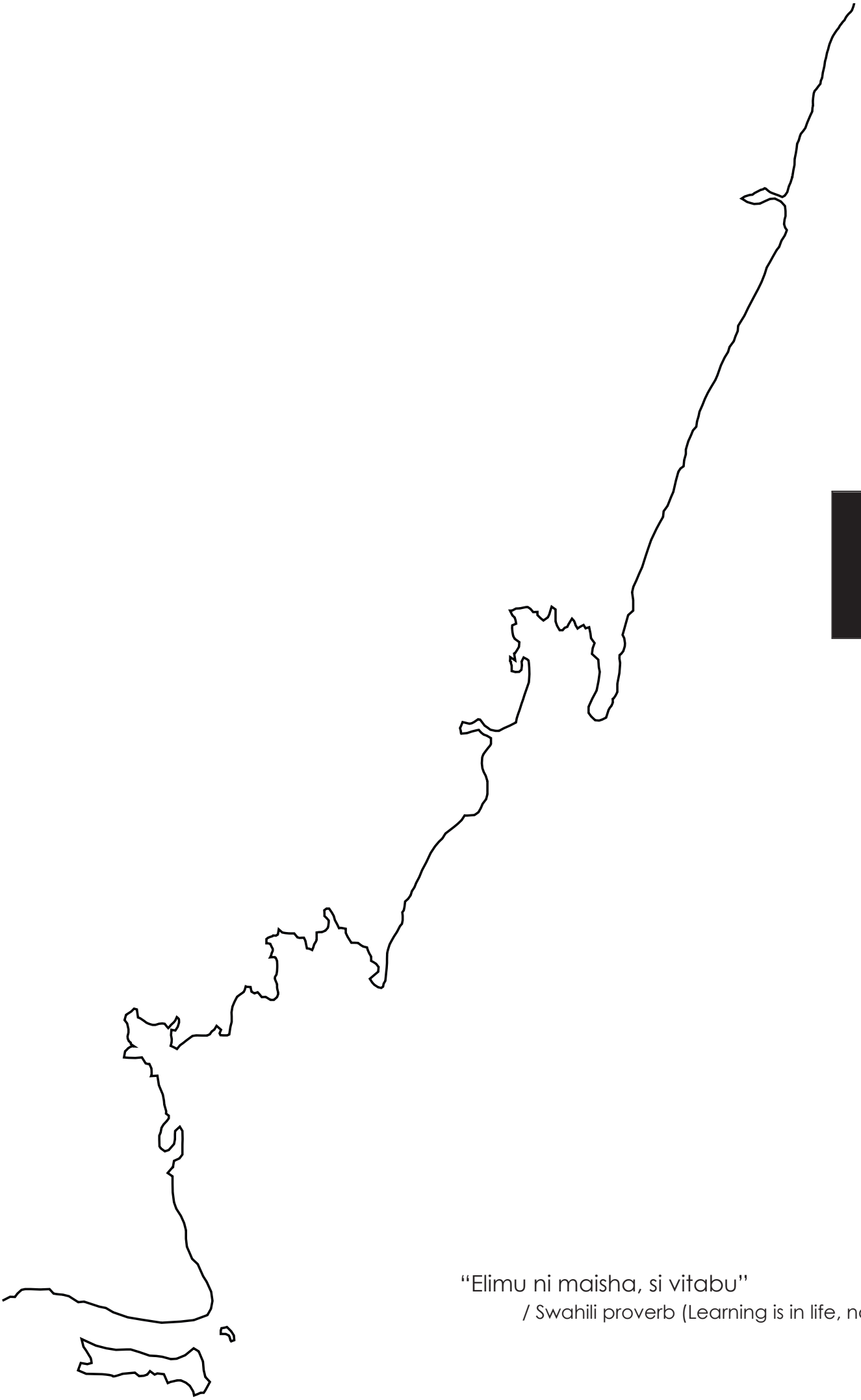
Stevensson, N.J. (1997) Disused shrimp ponds: option for redevelopment of mangroves. *Coastal Management* **25**: 425-435.

Tri, N.H., Adger, W.N. & Kelly, P.M. (1998) Natural resource management in mitigating climate impacts: the example of mangrove restoration in Vietnam. *Global Environmental Change* **8**: 49-61.

Valiela, I., Bowen, J. & York, J.K. (2001) Mangrove forests: one of the world's threatened major environments. *Bioscience* **51**: 807-815.

Walters, B.B. (2000) Local mangrove planting in the Philippines: are fisherfolk and fishpond owners effective restorationists? *Restoration Ecology* **8**: 237-246.

Walters, B.B. (2003) People and mangroves in the Philippines: fifty years of coastal environmental change. *Environmental Conservation* **30**: 293-303.



III

"Elimu ni maisha, si vitabu"

/ Swahili proverb (Learning is in life, not in books)

Crona, B.I. 2006 Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan coastal seascape. *Ecology and Society* 11(1): 32. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art32/

Research

Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan coastal seascape

Beatrice I. Crona[1]

ABSTRACT. The heterogeneous nature of even small communities has been acknowledged yet how such heterogeneity is reflected in local ecological knowledge (LEK) among groups of resource users in a community is poorly studied. This study examines the ecological knowledge held by fisher groups using differing gear and operating in different subsystems of a coastal seascape in south Kenya. Knowledge is compared to that of non-fishing groups and is analyzed with respect to the scales of ecological processes and disturbances affecting the ecosystem to identify mismatches of scale between local knowledge and ecological processes as well as points of convergence upon which emerging scientific and local community information exchange can build and develop.

Results reveal significant differences in the level and content of ecological knowledge among occupational categories with respect to the scale and nature of ecological interactions in the seascape. Non-fishing related groups were marked by consistently low levels of knowledge and understanding of all seascape components and processes. Gear defined fisher groups appeared linked, through fishing methods, to specific functional groups defined by trophic level although acknowledgment among users of trophic links and ecosystem effects were not always apparent.

Knowledge appeared to be largely related to maximization of resource extraction rather than reflecting deep understanding of ecological processes and causal links. Demographic changes and erosion of traditional management systems may partly explain this. Based on the results it is suggested that future investments geared at enhancing socioeconomic standard (e.g. through investment in improved gear) run the risk of further propelling the system down the poverty trap through habitat degradation and stock depletion, if not simultaneously combined with support for development and enhancement of existing LEK.

Key Words: *heterogeneous, local ecological knowledge (LEK), seascape, Kenya, East Africa, artisanal fishery*

INTRODUCTION

It has been argued that sustainable use of ecosystems depends on ecological knowledge, flexible institutions and adaptive organizations (e.g.Ostrom 1990, Olsson and Folke 2001, Ostrom 2005). Simultaneously community based management (CBM) is haled across many parts of the world as a potential solution where past, conventional governance has failed (Hulme and Murphree 1999, Goldman 2003, WRI 2005). CBM prescribes the active involvement of stakeholders but often fails to recognize the heterogeneous nature of even small communities (Agrawal 1997). A heterogeneity that may also be reflected in

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the local ecological knowledge (LEK) harbored by different user groups (Ghimire et al. 2004). LEK may be a mix of scientific and practical knowledge, it is site-specific and often involves a belief component (Olsson and Folke 2001). The idea of using such knowledge to enhance ecosystem management is well established (Berkes et al. 1995, Johannes 1998, Scoones 1999, Colding and Folke 2001, Drew 2005) and has been successfully implemented in several cases (Olsson and Folke 2001, Becker and Ghimire 2003, Aswani and Hamilton 2004). However, environmental governance depends on good, trustworthy information about the internal dynamics of the resource system (Dietz et al. 2003) and this information must match the scale of environmental events and decisions (Young 2002). In Kenya initiatives towards participatory monitoring for the management of coastal resources have recently emerged (Obura et al. 2002b) with the aim of including local fishermen in monitoring and management (Alidina 2005). In the coastal fishing community of Diani-Chale, south Kenya, Glaesel (2000) found that, in spite of cultural and religious homogeneity, social group identification was strongly based on occupation, in turn related to the use of specific fishing gear. Furthermore, in an artisanal fishery setting, gear type will dictate where the principal fishing effort is spatially located in the seascape thus likely affecting the type and scale of ecological knowledge accumulated. This study, therefore, sets out to describe and compare the ecological knowledge held by groups using differing gear and operating in different subsystems of a seascape on the south Kenyan coast. Furthermore local ecological knowledge held by the community is analyzed with respect to the scales of ecological processes and disturbances affecting the ecosystem to identify mismatches of scale between local knowledge and ecological processes as well as points of convergence upon which emerging scientific and local community information exchange can build and develop.

While authors have argued for the potential complementarities between LEK and science in resource management (Moller et al. 2004) any fruitful combination of the two knowledge systems requires, as a first step, an inventory of existing knowledge to identify points of convergence as well as gaps of information. Existing knowledge and understanding of ecological systems among user groups will also provide a stronger incentive for sustainable management of the resource. In addition, since institutional reform is argued by some to be a slow process (North 1990, Putnam 1993), it would seem feasible to build emerging local and scientific collaboration and information exchange on already existing institutions. Using North's (1990) broad definition of institutions this paper argues that the social groups among fishermen defined by gear (Glaesel 2000), constitute a type of informal institution as well as a framework within which LEK is generated and maintained. Although abundant studies of LEK exist few have attempted to systematically compare the knowledge of user groups within the same social-ecological system (Ghimire et al. 2004) and studies of LEK relating to coastal resources in general, and East Africa in particular, are scant (Tobisson et al. 1998, de La Torre-Castro and Rönnbäck 2004). Considering the emerging interest in involving local stakeholder groups in management as monitors based on their knowledge (Obura et al. 2002a) a good understanding of the distribution of LEK among members of the fishing community would seem a valuable base on which to build future management progress. This paper attempts to add to this understanding

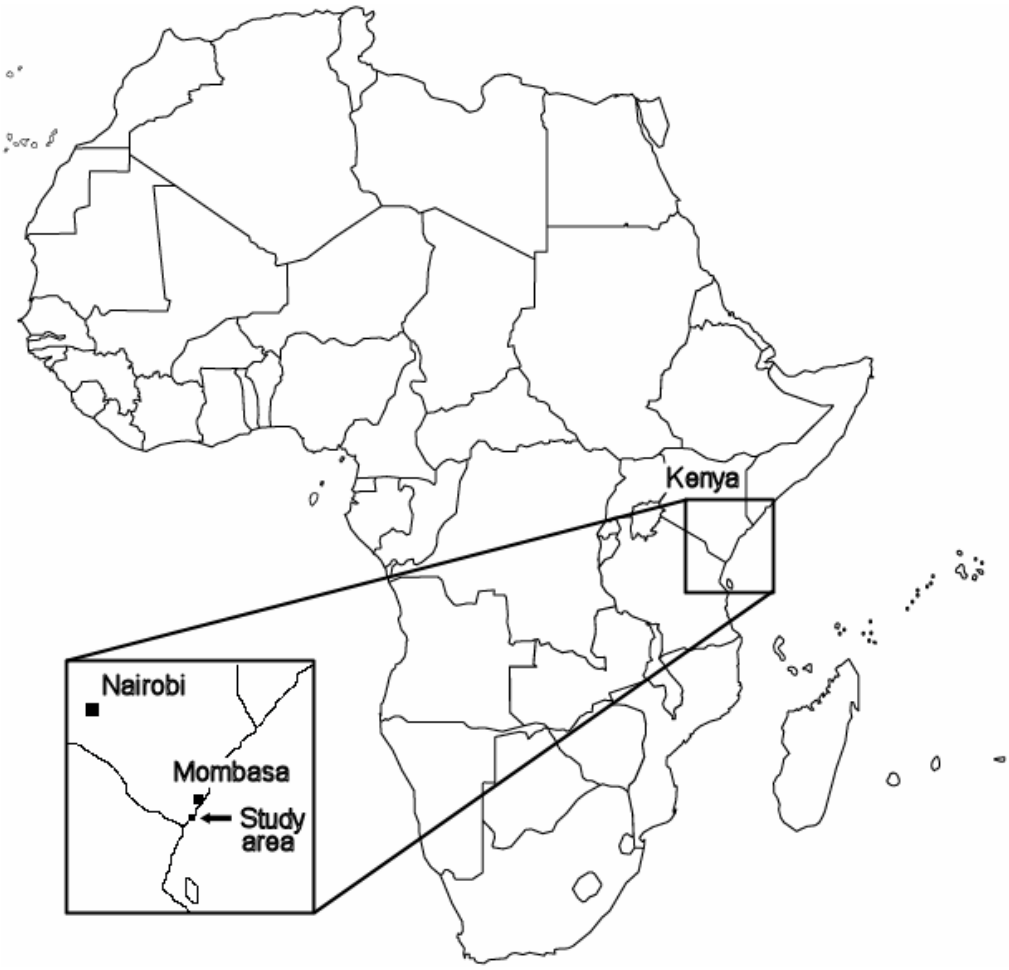

Figure 1. Map of the study area with the target community indicated in the inset of the left hand corner. The area is located on the southern Kenyan coast at 4°25'S and 39°50'E, approximately 50 km south of Mombasa.

by systematically comparing LEK across groups of resource users.

DEFINITIONS

In this paper LEK is defined according to Olsson and Folke (2001) as knowledge held by a specific group of people about their local ecosystems. As noted above it may be a mix of scientific and practical knowledge, it is site-specific and often involves a belief component. Consequently LEK differs from traditional ecological knowledge (TEK) in that it often lacks the dimension of historical and cultural continuity (Olsson and Folke 2001). Such is the case in this study where traditional belief systems have gradually been replaced by Islam (Glaesel 1997) and local communities have experienced a large influx of immigrants in recent decades. Ecosystem management is a systems approach to the management of natural resources (Christensen et al. 1996). Its

primary goal is the sustainable use of resources such that vital ecological functions and processes are maintained. It also recognizes that ecological function depends on ecosystem structure and diversity, that ecosystems are spatially and temporally dynamic, and the importance of adaptive learning for effective resource policy development in response to such dynamics. Building on these ideas Dale et al. (2000) defined five principles as important for ecosystem management; time, species, place, disturbance and landscape. As in Olsson and Folke (2001) these principles are used here for comparison with the knowledge of local resource users to analyze and discuss differences in the temporal and spatial scales of ecological knowledge held by different user groups about their resource base. This resource base comprises the interlinked coastal ecosystems of coral reefs, seagrass beds and mangroves and will hereafter be referred to as the coastal seascape (after Ogden and Gladfelder 1983).

CULTURAL AND INSTITUTIONAL CONTEXT

The area of focus is a rural fishing village located 50 km south of Mombasa in Kenya (Fig 1). It has approximately 200 households and an estimated 1000 inhabitants. The ecological system is characterized by mangroves covering 615 ha with mudflats and seagrass meadows in the shallow part of the lagoon, in turn sheltered from wave impact by shallow reefs at the mouth of the bay (Fig 2). The use of resources in the village is centered around fishing and to some degree the use of mangroves for poles and firewood. Other non-forest products are also taken from mangroves but government restrictions in the form of a cutting ban has periodically impeded extraction of wood products by locals (Dahdouh-Guebas et al. 2000). A majority of households depend primarily on fishing for their livelihood. The local artisanal fishery is based on gears such as seine nets, different types of gillnets, spearguns, and handlines; methods which have all been found to be spatially separated on a local geographical basis (Obura et al. 2002b) (Fig 2). Such spatial differentiation is a feature of many artisanal fisheries (Johannes 1981) and is likely to have an effect on the interactions among users as well as the local ecological knowledge harbored by user groups (Davis et al. 2004). The local fishery focuses on finfish but also includes various crustaceans and mollusks such as juvenile penaeid shrimps fished only by women and sold at local markets. Data collected in a parallel study (Crona and Bodin 2006) shows that 25% of households receive remittances (economic subsidies from kin outside the village) in the form of money or commodities and that 75% of these are represented by young (20-30 years) and old (50+ years) households (based on the age of the head of household). In addition, 37% of households are recent immigrants and the majority of these originate from Tanzania, where they return on a regular basis. Many Tanzanian fishermen reside in the village on a semi-permanent basis such that they return to their homeland during seasons of low fishing activity. Migration is linked to both economic factors and kinship ties. During high season migrating fishermen return to the study area to fish and are often assisted with travel expense and permits by local middlemen (fishmongers) operating out of the village. At the same time, kinship ties play a significant role in who is recruited to come along as crew for the duration of the season. The social ties governing patterns of migration and fishing pressure in the area are treated in detail in a forthcoming paper (Crona et al. forthcoming).

Livelihood strategies under changing conditions

The coast of Eastern Africa has a long history of influences from foreign cultures such as India, Malaysia and Greece. Today the population of coastal Kenya is comprised of two main ethnic groups; the Mijikenda of Bantu origin and the Swahili who are of mixed Bantu, Asian and Arabic descent (King 2000). The Mijikenda comprise nine tribes, of which Digo is the predominant ethnicity of inhabitants in the study area. Historically the Mijikenda were farmers and started their relation to the Swahilis as traders of agricultural products but as a consequence of colonial land access policies and politics in the early 20th century the Digo were forced to abandon traditional shifting cultivation and convert to Islam which led to a need to diversify their livelihood (Ng'weno 1995).

Since Digo people developed their dependence on fishing over a relatively short period in response to declining land access it is argued by some that traditional institutions used to govern their fishing related activities were not sufficiently embedded to persist through changing social and ecological conditions (King 2000). This is supported by Glaesel (2000) describing the undermining of local institutions for managing the common fishery in the early to mid 1900's as a combination of factors including the strife of the Kenyan government to develop the marine fishing industry, the parallel rise of coastal tourism attracting large numbers of unskilled labor and skilled, knowledgeable fishermen abandoning the occupation for more lucrative ventures. The vast majority of newcomers (primarily young men) seeking employment were not absorbed by the tourist industry and turned to speargun fishing as a mode of self-employment (Glaesel 1997). This fishing technique required low capital gear investment and was freed from the apprenticeship and kinship ties traditionally associated with other gear types. Another strain on the traditional management system has been the dramatic influx of Tanzanian fishermen after the 1964 overthrow of the Zanzibar-Pemba government resulting in large seine crews establishing more or less semi-permanent operations along the Kenyan coast (Glaesel 1997). Records show that, although currently classified as illegal, spearguns and seines have increased in proportion to other fishing methods in the area (McClanahan et al. 1997, Glaesel 2000).

Current management and policy environment

Gradual weakening of traditional governance structures coupled with a national top-down view of legislation with heavy focus on regulatory measures but without sufficient capacity for enforcement (GOK 1991, 2001) has led to a situation where the inshore fishery along the southern Kenyan coast is a virtually open access system (Alidina 2005). This has led to over-fishing and depletion of inshore stocks (Ochiewo 2004). Mangroves have also suffered and intensive mangrove timber extraction reached a maximum in the 1970's leading the government to impose a mangrove cutting ban which has since been in force on and off. The lifting of this ban is currently under review (Kwale District Forestry Officer pers com) and in the Forest Act (GOK 1994) community involvement in management of resources is suggested as a future goal. In response to the fisheries situation recent initiatives have been taken by, for example, forming the Diani Chale Management Trust (DCMT) just north of the area of focus in this study (Fig 1). This umbrella group (Becker and Ostrom 1995) includes representatives from local

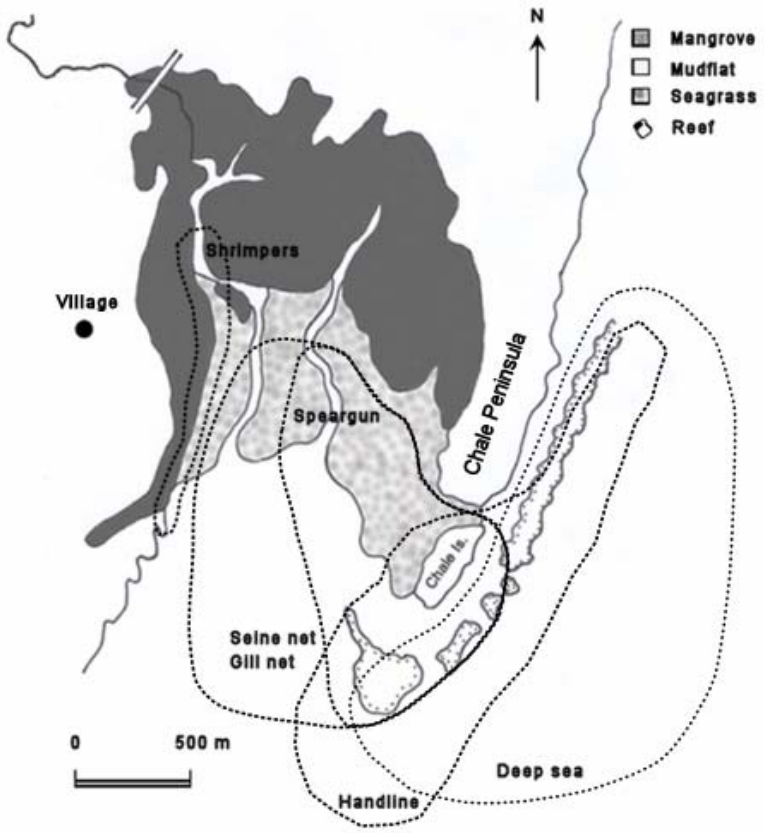

Figure 2. Map of the coastal seascape in focus. The respective distribution of mangroves, mudflats, seagrass beds and reefs is indicated. The area of primary fishing effort for each fishing related occupational category is marked with dotted lines showing the geographical distribution of fishing areas at a local scale. The occupational categories associated with each area are indicated in the figure.

community based organizations, community leaders, local administration and government agencies and has set as a goal to be the coordinator of Integrated Coastal Area Management in the area. The exact role of DCMT in fisheries management has yet to be articulated but information about the state of the fishery on a day-to-day basis is suggested to greatly improve the potential for flexible and sustainable management of the resource (Alidina 2005). The fact that they spend long hours actively observing the resource would seem to make fishermen well suited to undertake such monitoring, bearing in mind however, that without institutions allowing fishers to also monitor the behavior and extraction of others, few incentives will exist for them to accurately report their actions or the status of the resource.

METHOD

The aim of this paper is to investigate the existence of local ecological knowledge of different user groups (occupational categories) based on their primary gear type (Fig 2).

To collect data on ecological knowledge focus group and individual interviews were conducted. Thirteen groups were interviewed, complemented with 19 individual interviews (7 middlemen (fishmongers), 6 local businessmen, 4 farmers and 2 retired fishermen/elders), over a period of four months in 2004 (March – May) and 2005 (Sept – Oct). Each focus group contained between four and six participants, interviews lasted between 2-2½ hours, and groups were selected based on interviews with the village chairman and fishermen at the local landing site. A total of 62 persons participated in the focus groups. In most cases a captain was approached and asked to participate along with members of his crew (see Appendix 1 for additional details on respondent selection).

A segmented sampling design was used with replication of each category in the following way; three groups of deep sea fishermen, seine net fishermen and gill net fishermen respectively; three groups of women fishing shrimp, and one group each of handline and speargun fishermen as these men work primarily alone and not enough individuals were resident in the village to gather more than one group of each category. A more detailed description of occupation category attributes and respondent selection is given in Appendix 1. Individual interviews were similarly analyzed and compared based on occupational category of respondents. To be able to compare knowledge among these categories a semi-structured interview guideline was used (Morgan 1998). The start of each discussion centered on general topics such as why they had chosen their profession, how long they had been doing it as well as their thoughts on knowledge transfer to younger generations. The main discussion focused on two topics 1) their knowledge of species and ecological processes in the bay and 2) acknowledgment of changes in the ecosystem over time and understanding of ecological processes and links among seascape components. Throughout the discussion map-drawing and time-lines were used as aids for the groups to discuss the issues at hand. Knowledge was determined as representative for the gear category, and included in the subsequent analysis, only if mentioned at least three times by separate groups (see Davis and Wagner 2003 for further methodological discussion). Swahili folk systematics for fish and other target organisms is largely under-differentiated, meaning that one folk generic taxon refers to several scientific species of the same genus (Berlin 1973). Therefore species are only discussed where their identification has been clearly established through pictures or live specimens in conjunction with interviews. All interviews were conducted in Kiswahili (see Appendix 1 for details on interview set-up and translation).

RESULTS

Interview discussions showed the fishing profession to be viewed largely as a social cushion absorbing both young and old as unemployment is widespread. This contributes to the fishing occupation loosing its former status as a profession associated with high knowledge and experience. Analysis of knowledge furthermore revealed significant differences in the level and content of ecological knowledge among occupational categories with respect to the scale and nature of ecological interactions in the seascape. Non-fishing related groups were marked by consistently low levels of knowledge and understanding of all seascape components and processes. Gear defined fisher groups appeared to be linked, through fishing methods, to specific functional groups defined by trophic level although acknowledgment among users of

Table 1. Species targeted by fishermen using differing gear types and operating within distinct sub-systems of the coastal seascape. Functional groups of target organisms are based on trophic level. Dietary preferences and trophic level are based on Froese et al. (2004: Fishbase).

User group	*Deep Sea*	*Seine net*	*Gillnet*	*Handline*	*Speargun*	*Shrimpers*
Species targeted	Carangidae (P) Scombridae (P) *Selar* sp. (P) Squid (P) *Lethrinus* sp. (BP) Scaridae (H) *Siganus* sp. (H)[1] *Caesio* sp. (Pl) *Hyporamphus* sp. (O)	Carangidae (P) *Caranx* sp. (P) Scombridae (P) *Selar* sp. (P) *Sphyraena* sp. (P) Squid (P) *Strongylura* sp. (P) *Lutjanus argentimaculatus* (BP) *Lethrinus* sp. (BP) *Pomadasys* sp. (BP) Mugilidae (H, P) *Siganus* sp. (H)[1, 2]	*Sphyraena* sp. (P) *Strongylura* sp. (P) *Gerres* sp. *(BP)* *Lethrinus harak* (BP) *Siganus* sp. (H)[1, 2] Mugilidae (H, P) *Chanos chanos(O)*	*Carcharinus melanopterus* (P) *Makaira indica* (P) Scombridae (P) *Sphyraena* sp. (P) *Rhyncobatus djiddensis* (BP)	*Caranx* sp. (P) Scombridae (P) Squid (P) Scaridae (H) *Siganus* sp. (H)[1] Lobster (O)	Conch shells (D) Juvenile Penaeidae (D)
Functional groups	Pelagic/demersal predators (P) Benthic predators (BP) Herbivores (H) Planctivores (Pl) Omnivores (O)	Pelagic/demersal predators (P) Benthic pred (BP) Herbivores (H) Planctivores (Pl)	Pelagic/demersal predators (P) Benthic pred (BP) Herbivores (H) Planctivores (Pl) Omnivores (O)	Apex predators (P) Benthic pred (BP)	Pelagic/demersal predators (P) Herbivores (H) Omnivores (O)	Detritivores (D)
Seascape sub-system	Outer reef slope	Reef and lagoon	Lagoon	Outer reef slope, reef and lagoon	Reef and lagoon	Intertidal seagrass beds and mangrove channels

[1] = reef associated
[2] = seagrass associated

trophic links and ecosystem effects were not always apparent. Below follows a detailed account of the analysis under each theme outlined above.

The importance of ecological knowledge and knowledge transfer

The majority of respondent groups deemed it important to pass on their knowledge to their children. There is a tradition of children accompanying their parents and learning by observation and participation rather than theoretical or formal instruction, for both fishing and farming related activities. Similarly, new crew members are often trained by their captains or elder crew members. While the knowledge is stressed as important most fisher groups state that formal schooling should be prioritized and only in cases where this does not lead to a regular job should fishing be pursued. Fishing is thus viewed as a cushion to fall back on when other modes of income have failed and can also function as a social support network, providing young people alternatives to engaging in substance abuse or criminal activity. Such attitudes bear witness to the declining status of the fishing profession also observed by Glaesel (1997, 2000).

Knowledge of species and ecological processes in the bay

This section was introduced by asking participants to list the species judged to be most valuable to them, taking into

consideration the anticipated price at sale, the perceived abundance and the proportional importance of the species to their daily catch. This was to establish if the target species of the groups differed and if such differences could have any bearing on their subsequent knowledge of the ecological system in which they operate.

The deep sea and seine net fishermen target similar species consisting primarily of larger pelagic species such as Scombrids (mackerels and tunas) and Carangids (kingfish) but also more reef bound genera like *Caesio* sp., *Lethrinus* sp., *Lutjanus* sp. and *Siganus* sp.. The fish targeted by seine net crews included a higher proportion of lagoon and reef bound species (Table 1). Even though seine net fishermen have a stronger focus on the inner parts of the reef and the lagoon while deep sea fishermen concentrate on stocks well outside the reef, there was considerable overlap in the target areas (Fig 2).

The remaining groups differed considerably in their primary target species with handline fishermen focusing on large predators, such as sharks, while speargun fishermen selectively catch large individuals of many species on the reef including Carangids, Scombrids and Siganids (Table 1). Women target juvenile shrimp and catch fish only as by-catch.

In-depth discussions on the ecology (spawning, ontogenetic migration, trophic groups etc) of each target species was conducted to get an appreciation of the level of detail in ecological knowledge that the groups held about these species (Fig 3). Deep sea fishermen generally had a very good conception of where targeted species or taxa spawn, if they migrate to inshore nursery areas and if they also migrate regionally according to season. However, when asked about feeding habits only 65% of answers related to their listed species were in line with scientific information (Froese and Pauly 2004: Fishbase). Seine net, gill net, handline and speargun fishermen similarly had a fair knowledge of the ecology of their target species and over 80% of their answers of fish feeding habits agreed with Fishbase information. Women fishing groups (shrimpers) target only juvenile penaeid shrimps and other listed species are merely by-catch. Answers showed a fair agreement with known dietary information for juvenile shrimp (67%) but dietary information on by-catch species to corroborate answers was difficult to obtain as little information exists on juveniles of these species. Discussions with women also revealed a fragmented understanding of penaeid ecology and knowledge of ecology for by-catch species was poor. Since juvenile shrimps are transparent the women had observed that their gut is often brown and hence it was suggested that they eat mud. Similarly, in the majority of focus groups detritivorous species (crustaceans, molluscs and fish) were described by respondents as feeding on mud. Although most respondents could not give an accurate account of whether animals ingested the actual mud or organisms living in the mud such statements were considered as at least reflecting an understanding of the main dietary source of the target species. Discussions on animal feeding also revealed that respondents' knowledge of diets was based primarily on observations of gut content rather than direct observations of feeding.

Knowledge among middlemen included understanding of the mangrove, seagrass and reef components at generally high levels of detail. However, this occupational category consisted of respondents with varying backgrounds; all former fishermen but with varying experience and using differing gear. This was reflected in their equally heterogeneous knowledge such that respondents' knowledge tended to be similar

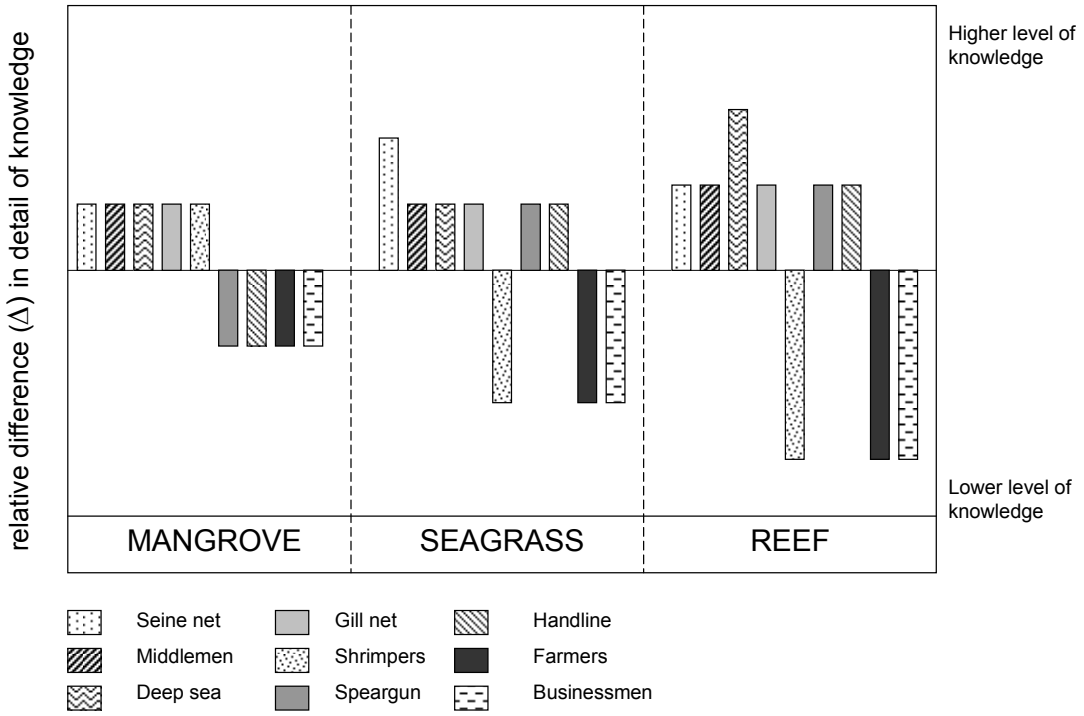

Figure 3. Relative difference in local ecological knowledge among different occupational groups operating in the target community. Knowledge is divided into three categories based on the three recognized sub-components of the coastal seascape; mangrove, seagrass and reef. Knowledge of different groups for each sub-component is represented as the relative difference of their level of knowledge compared to an estimated average level of knowledge for all groups (the baseline in the figure). Thus the bars represent each group's knowledge in relation to other groups. Amount of knowledge, for each occupational category, is ranked based on the expressed level of detail of ecological components and processes. Although groups may be represented as having equal levels of knowledge in terms of detail, the actual content of the knowledge may at times be related to different species depending for e.g. on which species are primarily targeted by a specific group.

in detail to that of the gear defined fisher group they previously belonged to.

Acknowledgment of changes in the ecosystem over time and understanding of ecological processes and links among components in the system

Six of eleven groups indicated there had been a decline in fish or shrimps over the years. The remaining groups, of which all were deep sea and seine net crews, did not perceive any such change in catches. Consequently these net fishermen seem less affected by decline of fish, at least in their own opinion. All of the women groups indicated a drastic decline of shrimp catch over the years. Neither group explicitly stated that there are now less shrimp but suggested lower catches are due to a larger number of fishing groups using the area and some being inexperienced groups disturbing

Table 2. Local ecological knowledge among groups of resource users (occupational categories) using different gear types and operating in distinct but overlapping sub-systems of a coastal seascape in Kenya. The knowledge is classified and related to the ecological principles defined by Dale et al. (2000)[a]. Occupational category is based on main gear type used and groups are listed in this column according to the ecological knowledge they were found to possess.

Ecological principle[a]	Knowledge of resource users reflecting each principle	Groups possessing this knowledge
Time Ecological processes function at different time scales, some long, some short; and ecosystems change over time.	- A clear understanding of the effects of clear-cutting of mangroves on related systems	Shrimpers Deep Sea Speargun Gillnet Middlemen Farmers* Businessmen*
	- Notions among respondents that fish stocks migrate along the coast and that such patterns are affected by seasonal monsoons[1]	Deep Sea Seine net Gillnet Middlemen
Species Particular species and networks of interacting species have key, broad-scale ecosystem-level effects.	- Knowledge of the keystone function of mangroves in coastal biological, hydrological and geomorphologic processes in the form of nursery habitats, water filtration and sediment stabilization.	All groups
	- Recognition of links between the ecosystems mangroves, seagrasses and reef	Deep Sea
	- Notion of trophic cascades due to changes in abundance of sea urchins, leading to over-grazing of seagrasses with potential effects on inshore fisheries.	Speargun* Seine net
Place Local climatic, hydrologic, edaphic and geomorphologic factors as well as biotic interaction strongly affect ecological processes and the abundance and distribution of species at any one place.	- Acknowledgement by respondents that seasonal climatic changes affect the distribution and abundance of shrimp and finfish in the area:	All groups
	- Seasonal monsoons and the resulting freshwater outflow attract juvenile shrimps into the mangrove system.	All groups
	- Seasonal monsoon related wind patterns and currents affect fish migrations along the regional coastline.	Deep Sea Seine net Middlemen Gillnet

Disturbance The type, intensity and duration of disturbance shape the characteristics of populations, communities, and ecosystems.	- Notion among some fishing groups that sea urchin aggregations can affect the dynamics of seagrass meadows and associated fauna.	Speargun* Seine net
	- Acknowledgement that historical and present land-uses, such as mangrove cutting will cause changes in the distribution and abundance of associated species (crabs, shrimp, fish) and ecosystem functions such as soil stabilization, water movement, nursery habitats, nesting areas and wind breakers.	Shrimpers Deep Sea Speargun Seine net Gillnet Middlemen Farmers* Businessmen*
	- Notion among some fishing groups that changes in climate (timing of the monsoon rains and El Niño phenomena) have occurred recently resulting in an effect on the artisanal shrimp fishery as well as mangrove coverage	Shrimpers Deep Sea Speargun Seine net Gillnet
Landscape The size, shape, and spatial relationship of land-cover types influence the dynamics of populations, communities, and ecosystems.	- Awareness of the nursery function provided by mangroves for fish and shellfish residing part of their life outside of the mangrove habitat. Shows a notion of the positive spillover effect of such functions on coupled ecological subsystems such as seagrass beds and coral reefs.	Shrimpers Deep Sea Speargun Seine net Gillnet Middlemen Farmers* Businessmen*

* groups exhibiting much less detailed understanding of links and processes

[1] Differences in scale of the fish migrations acknowledged by different groups. Deep Sea, Gillnet fishermen and Middlemen all perceive migrations on a local and regional scale while Seine net fishermen spoke only of fish migrations at a local scale in the bay.

and scaring off the shrimp. Per-capita shrimp catches have, nonetheless, unquestionably decreased. One reason put forth by seine netters as causing decline in fish stocks was a recent sea urchin infestation which they observed resulted in large areas of seagrass in the bay being completely removed through over-grazing. Such grazing aggregations of sea urchins have been observed in the Mombasa lagoon north of the study area (Alcoverro and Mariani 2002) and the potential for such aggregations to dramatically reduce seagrass or algal cover is well documented (Sala et al. 1998, see also Valentine and Heck 1999 for review). The causes of sea urchin aggregations have been proposed as highly successful recruitment (Rose et al. 1999) and anti-predatory benefits from dense aggregations in combination with reduced predation pressure from known predators like triggerfish (Balistidae) (McClanahan and Shafir 1990, Alcoverro and Mariani 2002). Intense fishing pressure in the area has drastically reduced fish populations in general and triggerfish populations in particular (McClanahan and Obura 1995) and it is likely that high sea urchin abundance may suppress recovery of fish populations since several of the targeted species are herbivores and compete with urchins for resources (McClanahan et al.

1994). The link between urchins, seagrasses and fishery was not acknowledgement by any other occupational category.

All but one category of fishermen (handliners) had a good understanding of the ecological link between mangroves and juvenile fish and shrimps (Table 2) while farmers and businessmen had consistently vague conceptions of these links. However, when asked to elaborate on the life history and specific ecological traits of shrimps the response differed. All except the handline fishermen claimed shrimp enter the system as juveniles during the seasonal rains but when asked about their distribution in the system the speargun fishermen and the women insisted on a markedly limited distribution compared to other groups, along with farmers and businessmen.

A similar discussion was conducted on crabs, as another major ecological component of the system. Knowledge of crabs (swimming crabs of commercial importance *Scylla serrata* and *Portunus pelagicus*) was similar across all fishing groups with the exception of speargun and handline fishermen who had slightly vaguer ideas of life history traits and non-fishing groups who showed a poor perception of these issues. Out of all respondents none but two of the middlemen recognized the pelagic life stage of the crab life cycle. One of these men had previously done work for a fisheries researcher in the area which may explain his more detailed knowledge. The other man could not recall where he had heard this nor ascertain its accuracy.

A concluding discussion on the effects of mangrove deforestation was conducted to investigate knowledge of ecological links between mangroves and surrounding ecosystems. Most groups had a clear understanding of the importance of mangroves as nursery areas for fish and shellfish. Only one group, the handline fishermen, did not see any connection of mangrove loss to fisheries, possibly as a result of the large predatory fish they target which may mentally decouple them from the mangrove resource. Interestingly, although showing understanding of the ecological importance of mangroves, neither of the net fishing groups could perceive any threats of mangrove loss to their own fishery, despite the fact that some of their target species are clearly linked to the mangrove-lagoon habitat.

Although all fishing related groups stressed the importance of mangroves for the direct goods and services they supply only women mentioned medicinal and religious uses. Farmers and businessmen had difficulty describing any related benefits apart from the nursery function and reduced soil erosion.

Perceptions of mangrove coverage from an historical perspective differed substantially between groups but a majority (over 70%) of fishing related groups mentioned El Niño as something causing the death of many mangroves. Most attributed it to the water dilution, others to the high temperatures. No published records exist on the effect of El Niño on mangroves in the area but several larger stands in the bay were severely affected in 1998 by sedimentation and oxygen depletion (Kairo pers com). Non-fishing groups had poor perceptions of both changes in mangrove coverage and potential causes.

The belief component is often cited as an important component in LEK or TEK (see e.g. Berkes et al. 1995, or Olsson and Folke 2001 respectively). In this study many respondents exhibited a mix of knowledge based on practical observations, knowledge acquired through training and religious beliefs. The religious aspect was most

prominent among some of the net fishermen groups who, for example, ascribed fluctuations in fish catches to the will of God, as illustrated by the following quote:

"Changes in fish catch are dependent on God's will. God can remove one species and transfer it to another place. Looking at fish stocks as declining or increasing is a human way of looking at it. It does not work that way, it's God's will."

DISCUSSION

Analysis revealed that LEK held by respondents ranged from detailed accounts of feeding of certain target species to acknowledgement of larger scale climatic changes affecting shrimp stocks and mangrove coverage. However, answers in general revealed a fragmented view of the seascape and at present appeared to be more related to maximization of resource extraction than deep understanding of ecological processes and causal links. Whether acknowledgement of such links did previously exist but were not essential to successfully extract resources due to lower fishing pressure cannot be fully explored here. The pattern is nevertheless supported by the present day lack of enforced taboos, closed seasons or exempted target species as well as the lack of formalized knowledge transfer resulting in poor coordination of knowledge and fragmented transfer over generations. Knowledge common to all groups included acknowledgement of the central role played by mangroves for coastal protection, water quality and as nursery habitat. The seasonal rains and related freshwater pulse affecting shrimp migrations were also recognized by all respondents although at varying levels of detail (Fig 3). Table 2 lists the five principles defined as important for ecosystem management by Dale et al. (2000) as well as the knowledge of local resource users reflecting each principle. Based on this table some differences can be discerned between groups with respect to the level of detail of ecological links and processes as well as notions of the scale (temporal and spatial) of these processes and their effects on ecosystem function (Fig 3). The following section will highlight these differences and discuss potential factors affecting the knowledge distribution among groups as well as its implications for the use of LEK in future management initiatives.

Heterogeneous knowledge distribution among gear defined groups

Handline fishermen, along with non-fishers, had a comparatively poor perception of climatic affects on mangrove coverage and shrimps recruitment while other respondents mentioned heavy rains, freshwater outflow and extreme temperatures, associated with El Niño in 1998, as principal causes. Of the handline fishermen interviewed only one had stayed permanently in the area for more than five years which explains the difficulty in seeing climatic effects on mangrove coverage. In combination with the fact that they target pelagic species and focus fishing efforts in the outer part of the seascape (Fig 2) it may also affect the lack of insight into shrimp migrations and distributions in the bay. That fishermen are familiar with the El Niño phenomena at all is most likely attributable to the fact that some were involved as labor in mangrove replanting initiatives conducted in the area, and in conjunction with this an information meeting was held in the village to describe the effects of the 1998 El Ninõ on the mangroves of the area.

Juvenile penaeid shrimps are the sole target species of fishing women. Any other fish caught is merely by-catch. Women also move in a limited area of the bay when fishing (Fig 2) as most cannot swim and are

restricted to shallow channels along the mangrove fringe where they use handheld scoop nets. Consequently they had a much limited view of the seascape (Fig 3). Even the perceived distribution and life history patterns of their main target species (shrimp) were limited compared to other fishing groups as they, like most other groups, base this knowledge solely on personal experience and observation. Speargun fishermen and non-fishers shared this view of distinctly limited shrimp distributions. Speargunners move over a much larger area of the lagoon than the women (Fig 2) but target lobster or larger size fish on the reef or nearby seagrass beds. This occupational category is also one of the fastest expanding groups in the area (McClanahan et al. 1997) due to the fact that many enter the profession as a last resort requiring little, if any, prior training or apprenticeship (Glaesel 2000). This may explain their less holistic view of the bay system compared to other fisher groups.

The deep sea fishermen (and to some extent also seine net fishermen) exhibit the broadest notion of system dynamics, acknowledging processes occurring on larger spatial and temporal scales such as regional fish migrations and climatic phenomena like El Niño affecting mangrove coverage through changes in rainfall. Captains heading large netting crews in deep waters carry a large responsibility and enjoy a high status among fishermen which is related to their perceived expertise. Such expertise is largely based on good understanding of both biological and physical processes relevant for resource extraction including winds, currents and weather patterns, which partly explains why groups headed by knowledgeable captains recognize ecological processes at larger scales than other groups like spear gunners (working alone) and women based solely inside the lagoon. The fact that deep sea and seine net fishermen did not perceive any large, long term changes in fish catches may be an effect of them fishing outside the reef, targeting more pelagic fish stocks which are sustained through population dynamics at a larger scale than the local seascape (Table 2) or because of religious beliefs, as shown previously. Unfortunately, analysis of the extent to which religion influences the worldview and perceptions of ecological processes of respondents lies outside the scope of this paper. The links between religious beliefs, worldviews and LEK may be complex but should be further studied in order to discern how they affect the conception of ecological knowledge and understanding.

Interestingly seine net groups, with a strong focus on the lagoon (Fig 2), were the only ones to acknowledge the interaction between sea urchin population explosions, declining seagrass meadows and fish abundance observed in the area. It indicates recognition of the link between seagrass coverage and some fish species targeted, such as *Siganus sutor* (African whitespotted rabbitfish) and *Leptoscarus vaigiensis* (Seagrass parrotfish). It also supports the idea that geographic location within the seascape will affect the type of knowledge accumulated by fisher groups since it is largely based on observations at a very local scale and it furthermore explains why deep sea and handline fishermen did not perceive this link. However, reasons for the sudden rise in sea urchin density could not be established by the seine net fishermen. From a scientific point of view drastic increases in sea urchin populations along the coast are believed to (among other things) be caused by stock depletion of predators like red-lined triggerfish (*Balistapus undulates*) and triple tail wrasse (*Cheilinus trilobatus*) (McClanahan and Shafir 1990, McClanahan 1995, Alcoverro and Mariani 2002).

Interestingly, neither of the groups interviewed mentioned triggerfish nor large wrasses as targeted species. This could be an effect of the interview set-up but may also reflect the very low current abundances of these species in the area as previously documented (McClanahan and Obura 1995). Although many groups reported fish diets that concurred fairly well with scientific information (although at a very general level) this knowledge was reportedly based on observations of gut content. Knowledge of diets is important ecological information but based solely on observation of gut content it is likely to reflect only a select part of the items ingested with a bias toward slowly degrading food items. This may affect perception of trophic linkages in the system and could explain why fishermen did not acknowledge the most probable cause of increasing urchin densities, i.e. lack of predation. Another reason such knowledge is not wide spread among fishers could be a loss of social memory among the active generation with respect to the ecological functions maintained by predatory fish, provided such knowledge previously existed. Lack of institutions for knowledge exchange in combination with influx of migrant and unskilled fishermen, as in the case of many deep sea fishermen and speargunners respectively, may also have contributed to the apparent knowledge dilution and memory loss after stock depletion. Although on different scales, parallels could be drawn between this observed pattern and the shifting baseline syndrome described by Pauly (1995). It means that new generations inappropriately base their evaluation of change in fish stocks and species composition on the levels existing at the time of their own entry into the profession, potentially masking gradual resource depletion.

Demographic changes influencing the nature of local ecological knowledge

As in the community studied here heterogeneity in knowledge distribution among resource user groups has been observed elsewhere (Ferguson and Messier 1997, Ghimire et al. 2004) and suggested implications for management include effects on communal views of system function as well as consensus with regards to the resource status (Ghimire et al. 2004, Moller et al. 2004). Capturing and comparing knowledge of different individuals and groups is inherently tricky but with methods designed to minimize error this paper nevertheless hopes to give an accurate representation of the body of LEK existing in the village. Given this, results show varying quality (i.e. level of detail) of group LEK related to the spatial user pattern of respective groups. Groups involved in resource extraction in a limited area of the seascape (e.g. shrimpers and handliners) have a higher level of LEK related to that particular sub-system but less detailed LEK for the other sub-ecosystems (Fig 3). At the same time groups with larger spatial range as well as overlap in spatial distribution, such as the net fishermen (Fig 2), have remarkably higher and similar levels of detail in LEK for each sub-ecosystem, even though the exact knowledge described, in turn related to their main target species, might vary from group to group.

Observed here were also several gaps of knowledge common to many groups. These gaps are related to scale and ecological linkages and include; poor understanding of fish migrations, life history patterns/migrations and divergent views on historical mangrove coverage as well as lack of insight into trophic linkages. In addition to group-specific localized fishing effort this could be explained by patterns of recent immigration, changes in the status of the

fishing profession and increasing numbers of young unskilled fishermen entering certain occupational categories. Recent immigration and the flexible or transient nature of the residence status of many Tanzanian fishermen in the village is likely to have an effect on the time horizons with which they view their resource consumption as well as the social memory of ecological processes based on past experience of local events mentioned earlier.

Remittances often allow for the substitution of goods and services previously extracted from the nearby environment and may result in a reduced appreciation of the need for common property resource conservation (Naylor et al. 2002). Although only 25 % of village households report receiving such subsidies the combination with substantial immigration may have served to erode LEK in the area. Historically, traditional Digo fisheries management included sacred sites, restrictions on gear use, fish size and fishing periods as well as fees for foreign fishers to access the fishing grounds (McClanahan et al. 1997). The past effectiveness of this traditional enforcement is not known but today it is limited, largely due to immigration and a belief among young fishers that such practices go against Islam. Changes in demographic structures and shifting belief systems are bound to have had a strong impact on the pool of LEK in the area. One can only speculate to what extent traditional management included a deeper understanding of causal ecological links by comparing with similar traditional management systems in other parts of the world (Johannes 1981, Aswani and Hamilton 2004) but it appears that current LEK is primarily used for maximization of resource extraction (seen through strong correlation between gear, group knowledge and target species). This could create a self-enforcing state of declining holistic knowledge and increasing decoupling from, and responsibility for, the communal resource. The somewhat fatalistic religious views expressed by many respondents with respect to fish stocks are another example which may have effects on incentives to conserve and, thus, for community based management.

Combining LEK and scientific knowledge for improved resource management

Although a large body of ecological knowledge exists within the fishing community at hand it is clear that certain limitations exist in identifying trends of ecological change at scales important for sustainable management. In a review of the strengths and weaknesses of local versus scientific ecological knowledge Moller et al. (2004) nevertheless point to the positive effects of combining the two knowledge systems for more effective resource monitoring and management. For example, they suggest that while science can offer the advantage of decoupling the sampling from harvests and provide studies of causation, inclusion of LEK can supplement science by increasing sample size and time series and help in the formulation of useful scientific hypotheses (Neis et al. 1999). Both knowledge systems suffer from the difficulty in capturing cross-scale linkages but combinations of the two may reduce uncertainties. While LEK is often poor in detecting shifts in average patterns of ecological parameters which may be more relevant or signal different concerns than extreme events, science is likely to miss occasional extreme events (captured by daily local observations) due to short sampling duration (Moller et al. 2004). The recognition by fishermen of extreme climatic events such as El Niño and its effect on reefs, shrimp populations, mangroves and seagrass coverage, is one example. Their

poor recognition of declining fish stocks, differing scales of fish migrations and lack of insight into causal relationships affecting the status of the seagrass meadows are also good examples of the potential for complementarities in combining science and LEK in this community. In a case study of the Ibiraquera Lagoon Seixas and Berkes (2003) identified factors weakening the resilience of the coupled social-ecological system. Breakdown of traditional institutions, rapid technological change in the form of spearguns and nylon nets, as well as rapid changes in the local socio-economic system by immigration all qualify as such factors and have been identified in this study. In combination with reported overfishing this indicates a system heading down a potentially negative trajectory. Key factors proposed to counterbalance this include cross-scale communication, sharing of facts about resource status and co-management using both scientific and local knowledge as a source of novelty and innovation (Seixas and Berkes 2003). LEK held by occupational groups in the studied community indicates a base on which to build such information exchange and may provide a source of resilience for the social-ecological system at hand provided gaps in LEK and links to scales of ecological processes are addressed and the direct link between gears (occupational categories) and certain ecological functions jointly recognized by resource users.

Initiatives for co-management are stirring in the area of coastal zone management in Kenya and while LEK should be viewed as a base to build on and involve stakeholder groups it is important to evaluate the strengths and weaknesses of such information to identify at which level scientific information can best complement existing knowledge. In a system where trust between scientists and local stakeholders has sometimes been under severe strain as a result of historical dealings between resource users and government agencies (McClanahan et al. 1997, Alidina 2005) it is important to find points of convergence; areas where science and LEK can meet and trust between local stakeholders and scientists built upon by mutual learning and exchange of information to enhance resource management. This will promote ownership into the management process and assessment of resource status among stakeholders (Neis et al. 1999). This study has identified a number of such areas as well as gaps of information where science can play an important, complementary role for sustainable management of coastal resources. The next step is to identify a forum where this exchange of information can take place on a continuous basis to allow for accumulation of LEK for improved management. The DCMT in Diani-Chale is a good example of such a forum as a local institution with an emerging mandate to address resource management issues and an active collaboration with the scientific community through CORDIO (Coral Reef Degradation in the Indian Ocean). Similar arrangements in this village and other fishing communities currently lacking strong local institutions could facilitate the process. The recently started Fishermen's Group initiated by local fishermen could perhaps be such a starting point; a step in the direction to increase and enhance local ecological information and social memory. This could help improve the knowledge pool in light of further socioeconomic and demographic changes and as such enhance the adaptive capacity of future management systems.

Concluding remarks

This study shows content and detail of ecological knowledge of occupational groups to vary and be linked to gear use.

Furthermore analysis of the knowledge suggests it may be based more on incentives to extract than incentives to conserve as no institutions have developed for transfer of knowledge of sustainable use or of critical ecological functions. The social-ecological system at hand suffers from many of the problems associated world wide with chronic poverty, such as increasing population pressure, high unemployment and degradation of natural resources. However, based on results presented here, investments geared at enhancing socioeconomic standard (e.g. through investment in improved gear) run the risk of further propelling the system down the poverty trap through habitat degradation and stock depletion, if not simultaneously combined with enhancement of existing LEK. Science may have an important role to play in this case but based on past experiences careful consideration of how this dialogue should proceed is advised. Investment in institutions for knowledge exchange that are credible and owned by all involved parties must be initiated prior to or in conjunction with any future investments to boost the social system based on marine resource extraction.

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LITERATURE CITED

Agrawal, A. 1997. *Community in conservation: Beyond enchantment and disenchantment*. Conservation and Development Forum, Gainsville, FL.

Alcoverro, T., and S. Mariani. 2002. Effects of sea urchin grazing on seagrass (*Thalassodendron ciliatum*) beds of a Kenyan lagoon. *Marine Ecology Progress Series* **226**:255-263.

Alidina, H. 2005. Local level fisheries management in Diani-Chale, Kenya: Current status and future directions. *Coastal Management* **33**(4):459-470.

Aswani, S., and R. J. Hamilton. 2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental Conservation* **31**(1):69-83.

Becker, C. D., and K. Ghimire. 2003. Synergy between traditional ecological knowledge and conservation science supports forest preservation in Ecuador. *Conservation Ecology* **8**(1).

Becker, C. D., and E. Ostrom. 1995. Human-Ecology and Resource Sustainability - the Importance of Institutional Diversity. *Annual Review of Ecology and Systematics* **26**:113-133.

Berkes, F., C. Folke, and M. Gadgil. 1995. Traditional ecological knowledge, biodiversity, resilience and sustainability. Pages 281-299 in C. A. e. a. Perrings, editor. *Biodiversity Conservation*. Kluwer Academic Press, Netherlands.

Berlin, B. 1973. Folk systematics in relation to biological classification and nomenclature. *Annual Review of Ecology and Systematics* **4**:259-271.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, J. F. Francis, J. A. MacMahon, R. F. Noss, and D. J. Parsons. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications* **6**:655-691.

Colding, J., and C. Folke. 2001. Social taboos: "Invisible" systems of local resource management and biological conservation. *Ecological Applications* **11**(2):584-600.

Crona, B. I., and Ö. Bodin. 2006. What you know is who you know? Patterns of communication as prerequisites for co-management. *Ecology and Society (In press)*.

Dahdouh-Guebas, F., C. Mathenge, J. G. Kairo, and N. Koedam. 2000. Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Economic Botany* **54**(4):513-527.

Dale, V. H., S. Brown, R. A. Haeuber, N. T. Hobbs, N. Huntly, R. J. Naiman, W. E. Riebsame, M. G. Turner, and T. J. Valone. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* **10**(3):639-670.

Davis, A., J. M. Hanson, H. Watts, and H. MacPherson. 2004. Local ecological knowledge and marine fisheries research: the case of white hake (*Urophycis tenuis*) predation on juvenile American lobster (*Homarus americanus*). *Canadian Journal of Fisheries and Aquatic Science* **61**:1191-1201.

Davis, A., and J. R. Wagner. 2003. *Who* knows? On the importance of identifying 'experts' when researching local ecological knowledge. *Human Ecology* **31**(3):463-489.

de La Torre-Castro, M., and P. Rönnbäck. 2004. Links between humans and seagrasses- an example from tropical East Africa. *Ocean & Coastal Management* **47**:361-387.

Dietz, T., E. Ostrom, and P. C. Stern. 2003. The struggle to govern the commons. *Science* **302**:1907-1912.

Drew, J. 2005. Use of traditional ecological knowledge in marine conservation. *Conservation Biology* **19**(4):1286-1293.

Ferguson, M. A. D., and F. Messier. 1997. Collection and analysis of traditional ecological knowledge about a population of arctic toundra caribou. *Arctic* **50**(1):17-28.

Froese, R., and D. E. Pauly. 2004. Fishbase. World Wide Web electronic publication. *in* version (06/2004). http://www.fishbase.org.

Ghimire, S. K., D. McKey, and Y. Aumeeruddy-Thomas. 2004. Heterogeneity in Ethnoecological knowledge and management of medicinal plants in the Himalayas of Nepal: Implications for conservation. *Ecology and Society* **9**(3):online.

Glaesel, H. 1997. *Fisher, Parks and Power : The socio-environmental dimentions of marine resource decline and protection on the Kenya coast. PhD Thesis*. University of Wisconsin-Madison.

Glaesel, H. 2000. State and local resistance to the exapnsion of two environmentally harmful marine fishing techniques in Kenya. *Society and Natural Resources* **13**:321-338.

GOK. 1991. *The fisheries act, chapter 378*. Government of Kenya, Nairobi.

GOK. 1994. *Kenya Forestry Master Plan*. Ministry of Environment and Natural Resources, Nairobi.

GOK. 2001. *The fisheries act, chapter 378 Susidiary Legislation*. Government of Kenya, Nairobi.

Goldman, M. 2003. Partitioned nature, privileged knowledge: community-based conservation in Tanzania. *Development and Change* **34**(5):833-862.

Hulme, D., and M. Murphree. 1999. Communities, wildlife and the "New Conservation" in Africa. *Journal of International Development* **11**:227-285.

Johannes, R. E. 1981. *Word of the lagoon: Fishing and marine lore in the Palau district of Micronesia.* University of California Press, London.

Johannes, R. E. 1998. The case for data-less marine resource management: examples from tropical nearshore fisheries. *Trends in Ecology and Evolution* **13**:243-246.

King, A. 2000. *Managing without institutions: The role of communication networks in governing resource access and control, Phd Thesis*. PhD. University of Warwick, UK.

McClanahan, T. R. 1995. Fish predators and scavengers of the sea urchin *Echinometra mathaei* in Kenyan coral reef marine parks. *Environmental Biology of Fishes* **43**:187-193.

McClanahan, T. R., H. Glaesel, J. Rubens, and R. Kiambo. 1997. The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. *Environmental Conservation* **24**(2):105-120.

McClanahan, T. R., M. Nugues, and S. Mwachireya. 1994. Fish and sea urchin herbivory and competition in Kenyan coral reef lagoons: the role of reef management. *Journal of Experimental Marine Biology and Ecology* **184**(2):237-254.

McClanahan, T. R., and D. O. Obura. 1995. Status of Kenyan coral reefs. *Coastal Management* **23**(57-76).

McClanahan, T. R., and S. H. Shafir. 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. *Oecologia* **83**:362-370.

Moller, H., F. Berkes, P. O'Brian Lyver, and M. Kislalioglu. 2004. Combining science and tradtitional ecological knowledge: monitoting populations for co-management. *Ecology and Society* **9**(3):online.

Morgan, D. L. 1998. *Planning Focus Groups*. Sage Publications Inc., London.

Naylor, R. L., K. M. Bonine, K. C. Ewel, and E. Waguk. 2002. Migration, markets, and mangrove resource use on Kosrae,

Federated States of Micronesia. *Ambio* **31**(4):340-350.

Neis, B., D. Schneider, L. Felt, R. Haedrich, J. Fischer, and J. Hutchings. 1999. Fisheries assessment: what can be learned from interviewing resource users? *Canadian Journal of Fisheries and Aquatic Science* **56**:1949-1963.

Ng'weno, B. 1995. *Reinventing ground rules: Inheritance of land among the Digo of Southern Kenya, MA Thesis*. Stanford University.

North, D. C. 1990. *Institutions, Institutional Change and Economic Performance (Political Economy of Institutions and Decision)*. Cambridge University Press.

Obura, D., S. Wells, J. Church, and C. Horrill. 2002a. Monitoring of fish catches by local fishermen in Kenya and Tanzania. *Marine and Freshwater Research* **53**:215-222.

Obura, D. O., I. N. Wanyoni, and J. M. Mwaura. 2002b. Participatory monitoring of an artisanal fishery in Kenya. Pages 70-82 in O. Lindén, D. Souter, D. Wilhelmsson, and D. Obura, editors. *Coral Reef Degradation in the Indian Ocean, Status Report 2002*. Cordio, University of Kalmar, Sweden.

Ochiewo, J. 2004. Changing fisheries practices and their social implications in south coast Kenya. *Ocean & Coastal Management* **47**:389-408.

Ogden, J. C., and H. E. Gladfelder. 1983. *Coral Reefs, seagrass beds and mangroves: their interactions in the coastal zone of the Caribbean*: *report of a workshop, held at West Indies laboratory, St. Croix, U.S. Virgin Island May*. UNESCO Report in Marine Science, No 23, Montevideo, US.

Olsson, P., and C. Folke. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken Watershed, Sweden. *Ecosystems* **4**(2):85-104.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.

Ostrom, E. 2005. *Understanding Institutional Diversity*. Princeton University Press, Bloomington.

Putnam, R. D. 1993. *Making democracy work. Civic traditions in modern Italy*. Princeton University Press, Princeton, NJ.

Rose, C. D., W. C. Sharp, W. J. Kenworthy, W. G. Hunt, W. G. Lyons, E. J. Prager, J. F. Valentine, M. O. Hall, P. E. Whitfield, and J. W. Fourqurean. 1999. Overgrazing of a large seagrass bed by the sea urchin *Lytechinus variegates* in Outer Florida Bay. *Marine Ecology Progress Series* **190**:211-222.

Sala, E., C. F. Boudouresque, and M. Harmelin-Vivien. 1998. Fishing, trophic cascades, and the structure of algal assemblages : evaluation of an old untested paradigm. *Oikos* **82**:425-439.

Scoones, I. 1999. New ecology and the social sciences: What prospects for a fruitful engagement? *Annual Review of Anthropology* **28**:479-507.

Seixas, C. S., and F. Berkes. 2003. Dynamics of social-ecological changes in a lagoon fishery in southern Brazil. Pages 271-298 in F. Berkes, J. Colding, and C. Folke, editors. *Navigating Social-Ecological*

Systems: Building resilience for complexity and change. Cambridge University Press, Cambridge.

Tobisson, E., J. Andersson, Z. Ngazi, L. Rydeberg, and U. Cederlöf. 1998. Tides, monsoons and seabed: local knowledge and practice in Chwaka Bay, Zanzibar. *Ambio* **27**(8):677-685.

Valentine, J. F., and K. L. J. Heck. 1999. Seagrass herbivory: evidence for the continued grazing of marine grasses. *Marine Ecology Progress Series* **176**:291-302.

WRI. 2005. *World Resources 2005: The Wealth of the Poor - Managing Ecosystems to Fight Poverty*. World Resources Institute in collaboration with UNDP, UNEP and World Bank, Washington, DC:WRI.

Young, O. R. 2002. *The Institutional Dimensions of Environmental Change: Fit, Interplay and Scale*. MIT Press, Cambridge.

APPENDIX 1: Additional description of methodology and data collection

Attributes of occupational categories

Nine different occupational categories were identified; businessmen (local entrepreneurs), farmers, middlemen and six occupational categories of fishermen (and women) defined based on primary gear type and fishing technique. Businessmen is a rather broad occupational category, which was defined based on a description by respondents of their livelihood as selling and/or buying any kind of goods such as food, groceries, building material and related services. Middlemen is the local term used for fishmongers, persons who buy fish from the fishermen directly at the landing sites and sell it on to a third party. Because their business is purely focused on fish they were distinguished from other businessmen. Furthermore, many middlemen were previously fishermen, a factor judged to potentially affect their LEK, wherefore they were separated as a distinct category. All fishing groups were defined by gear and respondents were included in each respective focus group category based on their reported primary occupation.

Focus groups were selected through interviews with the village chairman and fishermen at the local landing site in combination with validation of occupation among members of the community through data collected during a parallel study of social network(Crona and Bodin forthcoming). Due to his informal but central position, which provides him with in-depth knowledge of most households in the village, the chairman was approach and asked to identify as many persons as possible from each gear defined category. These persons were then approached at the local landing site and asked to further identify people from each category. All names were then cross-checked against the database on self-reported primary occupation gathered for the parallel study in an attempt to validate occupational membership. This was done as some fishermen may employ several techniques depending on season, although most will identify with one specific gear type when asked to state their primary occupation. From this list of names persons were then approach at random. For logistical reasons most often a captain was approached and asked to participate along with members of his crew. Most fishermen spend long hours out at sea and it became apparent that to gather random members of separate crews for each focus group was nearly impossible as each crew operate on their own schedule.

The interview set-up

The comparative advantages of individual versus group interviews vary depending on the purpose of the investigation. The use of focus groups in this study was motivated by several factors. First, focus groups provide interviewers with the ability to study interaction on a given topic, enhancing understanding of not only what participants think but also why they think this way (Morgan 1988). In this case I believed such interaction among fishermen in a group could lead to more elaborate, in depth information on ecosystem processes and could assist participants in formalizing their ideas. It also allowed me to observe group dynamics thereby evaluating to what extent captains potentially dominated the discussion. This appeared not to be the case wherefore results are judged to be representative of the entire group interviewed. Secondly, previous interaction among researchers, villagers and government officials in the area regarding management issues have shown that group discussion can be more productive than individual interviews as they enhance the confidence of individuals to speak their mind. Such lack of confidence may stem from the inherent

hierarchical positioning of the researcher and the respondent in a one-on-one situation due to ethnic, cultural as well as educational differences. Focus groups reduce the interaction with the interviewer and puts greater emphasis on inter-group communication (Morgan 1988).

All focus group interviews were conducted using a moderator (a Kiswahili speaking male scientist knowledgeable with respect to the nature of local fishing operations, target species and ecological characteristics of the bay). The author (conversant in Kiswahili but not entirely fluent) introduced the objective and set-up of the interview in Kiswahili and was present throughout the interview to help guide the process and follow up on specific questions of interest. In addition a translator was present to translate and clarify any issue that was not entirely clear to the author. The same set-up was used for interviews with women but in these cases more emphasis was placed by the author (also a woman) on the introduction and objectives of the interview to encourage the women to share their views and instill confidence.

Below is outlined the semi-structured interview guideline used for all interviews in the study:

Interview guideline

Introduction

Q: Let me ask, are you all from this village? (Respondents were asked to state their names, where they live, and for how long)
Q: How long have you been fishing (farming, doing business etc) in this area?
Q: Could you tell me a little about how and why each of you became a fisherman? (The question was asked to give a brief personal history of each group member)
Depending on the answers this was followed up with…
Q: Is that a common way of entering the profession?
Q: Does this mean that your sons/children will become fishermen as well? (The question was asked to give an indication of a potential changes in traditions, knowledge transfer and young people moving from village)
Q: How will all the knowledge you have be passed on to younger generations?
Q: Do you feel confident that the knowledge will be kept this way?
Q: Is it important that such knowledge is maintained and passed on to younger generations?

Topic 1- Knowledge of species and ecological processes in the bay

Q: Did you get a good catch today? What did you catch?
Q: Do you always catch this type of fish? If not what else do you normally catch? (A discussion around a representative composition of catch in terms of different species)
Q: Respondents were asked to identify the 10-15 most important fish species they catch taking into consideration the anticipated price at sale, the perceived abundance and the proportional importance of the species to their daily catch.
Q: Out of these 10-15, which 5 species do you judge to be the most important (based on anticipated price at sale, the perceived abundance and the proportional importance of the species to their daily catch)?
Q: Could you explain to me how the catch changes over the course of the year, from season to season, fort each of these five taxa/species?
Q: For each of the 5 taxa/species:

- Where do you catch it? At what time/season? Why?
- Are they adults?
- What about when they are young, where can you find them? Why?
- What do these fish eat at different stages of their life?

At this point the group was asked to draw a rough map of the area together with the interviewer. Specific sites and characteristic features on the map were discussed to ensure that the interviewer's perception of the area map agreed with the one held by the group. All group members were encouraged to get involved in the process. The map was then used to indicate primary target areas for the taxa/species identified in the previous questions.

Q: Do you use any bate when fishing? Where does it come from and how/why?
Q: Respondents were asked to identify 3 taxa/species of fish that they associate primarily with A) mangroves B) sea grass beds C) reefs.
(This question was used partly as a validation tool for knowledge of target species above but also as a measure of the how easily respondents of non-fisher categories could differentiate between fish taxa associated with different sub-systems of the coastal seascape)

Throughout the above discussion respondents were probed for clarifications and further explanations wherever appropriate and needed.

Shrimps
Q: Do shrimps come in the mangroves?
Q: If so why are they found in the mangroves?
Q: Are they big or small when they come in?
Q: Where (in the bay) are shrimps caught? Why?

Crabs
Q: Where do they live? And why?
Q: Do they live their whole life there? Explain. (The question was asked to reveal knowledge of the crab life cycle).

Q: What do you think would happen if most of the mangroves around the bay were cut down? Would it have any effect on the fisheries? If so, how? Do you know of any other effects of mangrove deforestation?

Topic 2- Acknowledgment of changes in the ecosystem over time and understanding of ecological processes and links among components in the system
Q: You say you have been fishing in the area for X years, have you noticed any changes in the type of fish/shrimps/crabs you catch or the area where fish/shrimp/crabs are caught?
Using of the map drawn previously to explain changes and patterns the following questions were asked:
Q: Have you perceived any change in mangrove coverage over the years? A discussion about coverage before, during and after the change (historical events were used to place the change in time). Respondents were asked to explain the process of change by drawing a time line indicating patterns of increasing and decreasing coverage over time.

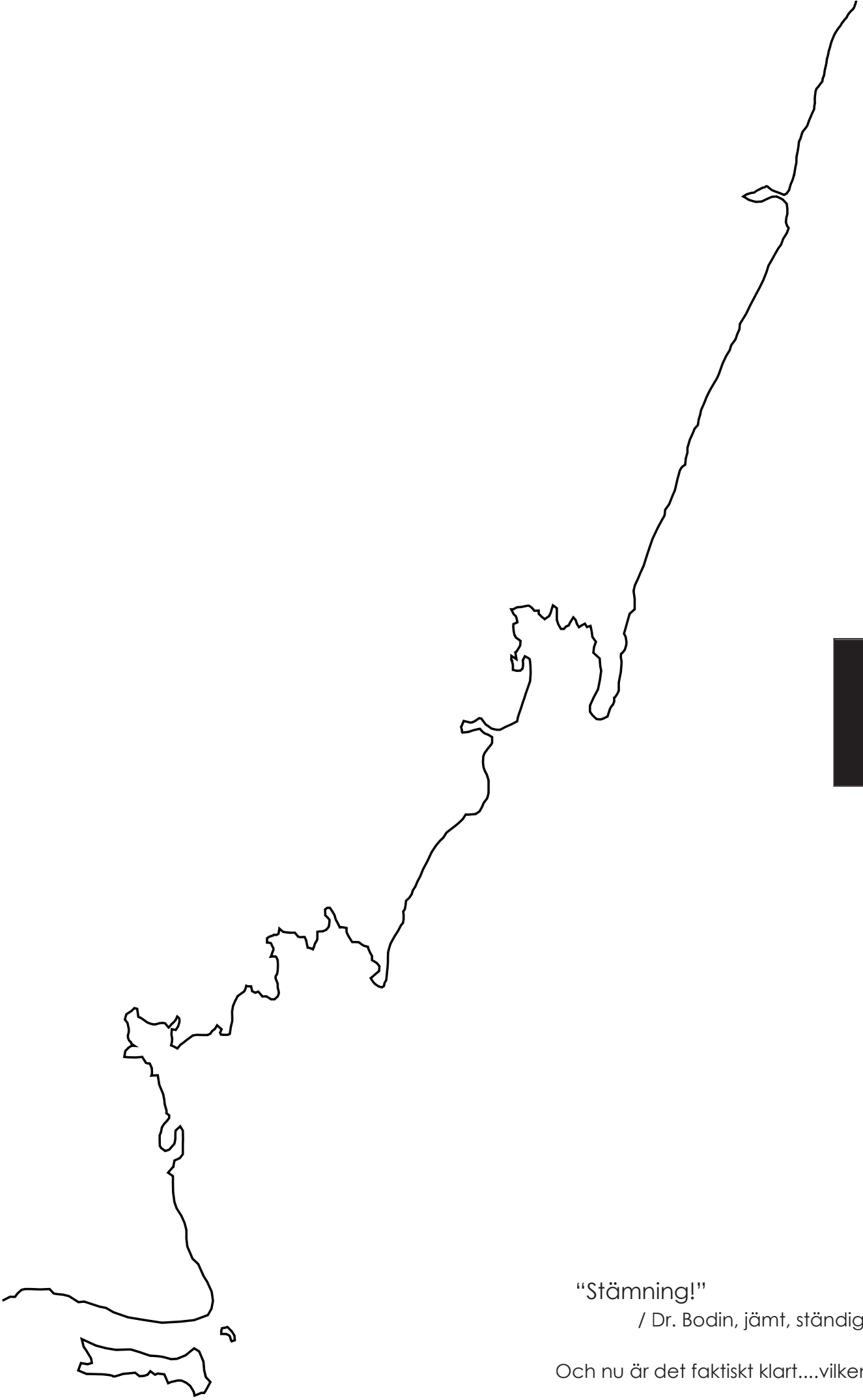
Q: Have you perceived any change in catches over the years? Respondents were asked to identify any changes in fish catches over time by drawing a time line (with assistance from the interviewer and moderator) and indicating patterns of increasing and decreasing catches over time.
Q: Can you tell me what you think may be the reason for this change?
Q: What solutions/actions can you suggest to improve the situation? (This was asked in order to further identify coupled social-ecological knowledge and ideas, i.e. recognition of institutional/organizational change needed for resource management)

Throughout the above discussion specific questions to follow up issues of importance were incorporated under each topic.

Literature cited:

Crona, B. I., and Ö. Bodin. forthcoming. What you know is who you know? Patterns of communication as prerequisites for co-management. *Ecology and Society*.

Morgan, D. L. 1988. *Focus groups as qualitative research*. Sage Publications Inc., Beverly Hills, CA.



IV

"Stämning!"

/ Dr. Bodin, jämt, ständigt och alltid.

Och nu är det faktiskt klart....vilken stämning!

WHAT you know is WHO you know? Communication patterns among resource users as a prerequisite for co-management

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ABSTRACT. Social networks are one factor determining the flow of information within communities and as such may be important in determining successful implementation of community based management. We mapped the social network used for communication of knowledge and information related to natural resource extraction among villagers in a coastal seascape in Kenya. We further identified subgroups and examined their inter-relations while measuring to what extents personal attributes such as occupation can explain observed group structure. Finally we compared the local ecological knowledge held by villagers of different occupations with the structure of the communication network to map how well this structure can explain distribution of ecological knowledge among them. Results show that communication occurs primarily between fishermen using the same gear type which may inhibit exchange of ecological knowledge within the community. This may partly explain why the community has been unsuccessful in regulating resource extraction, especially since potentially influential groups of non-fishermen have limited communication with the various fisher groups. Analysis of network structure also shows that groups most central, and hence potentially most influential, are dominated in numbers by migrant Deep Sea fishermen, hypothetically less motivated to initiate collective action for resource management. Hence, we conclude that lack of collective action to remedy an unsustainable situation may be attributed to various different but distinct aspects of the specific structure of the social network.

Key Words: *Social network; ecological knowledge; fisheries; East Africa; co-management; communication patterns; fishing gear*

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INTRODUCTION

The idea that natural systems are dynamic and inherently unpredictable is becoming increasingly established (Carpenter et al. 2001, Scheffer et al. 2001, Folke et al. 2004). Along with this, there is an emerging recognition that to effectively manage such uncertainty requires adaptive approaches and a system of continuous learning to interpret and respond to ecological feedbacks (Walker et al. 2002, Olsson 2004a). It is also well known that many communities of resource users possess intricate knowledge of their local resource base (Johannes 1981, Hunn et al. 2003, Ghimire et al. 2004) and that such localized ecological knowledge (LEK) can provide a valuable base for resource management (Johannes 1998, Becker and Ghimire 2003, Moller et al. 2004).

A management system that embraces adaptability and explicitly emphasizes the importance of the resource users' localized ecological knowledge is embodied in the concept of adaptive co-management (Gadgil et al. 2000). It combines the element of dynamic learning in adaptive management (e.g. Holling 1978) with collaborative management (e.g. Buck et al. 2001) linking groups of stakeholders for the joint management of resources (Olsson 2004a). But for adaptive co-management to work self-organization of stakeholders and collective action has also been suggested as vitally important (Olsson 2004a) and this in turn is influenced by the ability of the involved parties to agree on resource related problems and resource status (see Ostrom 2005 and references therein).

Communities are rarely just one single group of local stakeholders, rather they are defined by complicated patterns of subgroups with different perceptions, interests, resources and amount of influence (Carlsson and Berkes 2005, Nygren 2005). Furthermore, social psychologists and sociologist have long argued that individuals are most influenced by the people with whom they engage in frequent interactions, i.e. their primary groups (Cooley 1909, Festinger et al. 1950, Homans 1950, Kadushin 1966). This implies that individuals are likely to develop an understanding of the status of a natural resource similar to other members of the same stakeholder group. Hence, the scale and content of LEK should not be presumed to be uniformly distributed among resource users in a community. In fact, knowledge of ecological functions and processes may vary between groups of resource users as demonstrated by several studies (Hunn et al. 2003, Ghimire et al. 2004, Crona 2006).

If we assume that a reasonable level of mutual understanding of resource status increases the likelihood that stakeholders will organize and agree upon common rules for managing the resource (see Ostrom 2005 and references therein), then enabling members of different stakeholder groups to establish such a common understanding through inter-group relations, in the form of bridging ties, is crucial (e.g. Schneider et al. 2003). Hence, exchange of information and knowledge among stakeholder groups emerges as a fundamental element of successful management of natural resources. The existences of such bridging ties are, in addition, thought to be important for the community's potential for collective action (Granovetter 1973) and conflict resolution (e.g. Carlsson and Berkes 2005). Thus, the structural characteristics of the social network of individuals and groups in a community influence the potential for successful natural resource management by its profound effect on the diffusion of information and knowledge and therefore, indirectly, on the distribution and

variability of LEK among users (cf. Weimann 1982, Gould and Fernandez 1989, Abrahamson and Rosenkopf 1997, Reagans and McEvily 2003).

In this study, we mapped the social network used for communication of knowledge and information related to natural resources among different professionals and resource extractors operating in a coastal seascape in Kenya. This community was chosen as it has not been successful in regulating the inshore local fishery which has led to a system currently diagnosed as overexploited (McClanahan et al. 1997, Ochiewo 2004). Our objective was to investigate if lack of collective action to remedy this unsustainable situation may be attributed to the structures of the social networks in the community. The underlying assumption is that the distribution of LEK in the community, which is dependent on the network structure, affects the likelihood that the community will reach a common understanding of resource related problems at hand. This in turn affects their ability to self-organize around regulations of resource extraction.

To map the interaction patterns relating to the exchange of information and knowledge of natural resources among individuals in the community we used methods from the social sciences, with emphasis on the field of Social Network Analysis (SNA) (see e.g. Wasserman and Faust 1994, Scott 2000). This provided us with a toolbox to quantify various theoretically important structural characteristics of the social network. Using network analysis, we set out to test two hypotheses:

(1) Occupation, and more specifically gear defined fishing techniques among fishermen, is important in defining group membership in the community in relation to communication of resource related information.

(2) Social network structure can explain the distribution of common and group specific ecological knowledge among user groups. More specifically, groups with strong links between each other tend to have similar knowledge, in this case LEK.

Finally, we discuss the implications of our findings for adaptive co-management in the study area. We also present some hypothesis, using social theories that link network structure to social phenomena, on why the focus community has not succeeded in regulating their resource extraction. To our knowledge this study is one of the first attempting to use a quantitative analysis of empirical social relational data in research on adaptive co-management of natural resources.

METHOD

Area description

The area of focus in this study is a rural fishing village located approximately 50 km south of Mombasa in Kenya (Figure 1). It has approximately 200 households and an estimated 1000 inhabitants. The ecological system is characterized by mangroves covering approximately 5 km^2 with mudflats and seagrass meadows in the shallow part of the bay. The lagoon is

sheltered from intense wave impact by shallow reefs at the mouth of the bay (Figure 2). The use of resources in the village is centered around fishing and to some degree the use of mangroves for poles and firewood. Other non-forest products are also taken from mangroves but government restrictions in the form of a cutting ban has periodically impeded extraction of wood products by locals (Dahdouh-Guebas et al. 2000). A majority of the households depend primarily on fishing for their livelihood while farming and small scale businesses represent some alternative livelihoods. The artisanal fishery is based on gears such as seine nets, different types of gillnets, spearguns, handlines and, to a lesser extent, traps; methods which have all been found to be spatially separated on a local geographical basis (Obura et al. 2002)(Figure 2), a feature also found in other artisanal fisheries (Johannes 1981).

Data collection

The target population was defined as all households resident in the village for at least six months prior to data collection, and constituted 206 households. A nearly complete (83%) network data set was gathered based on interviews with the heads of, in total, 171 households

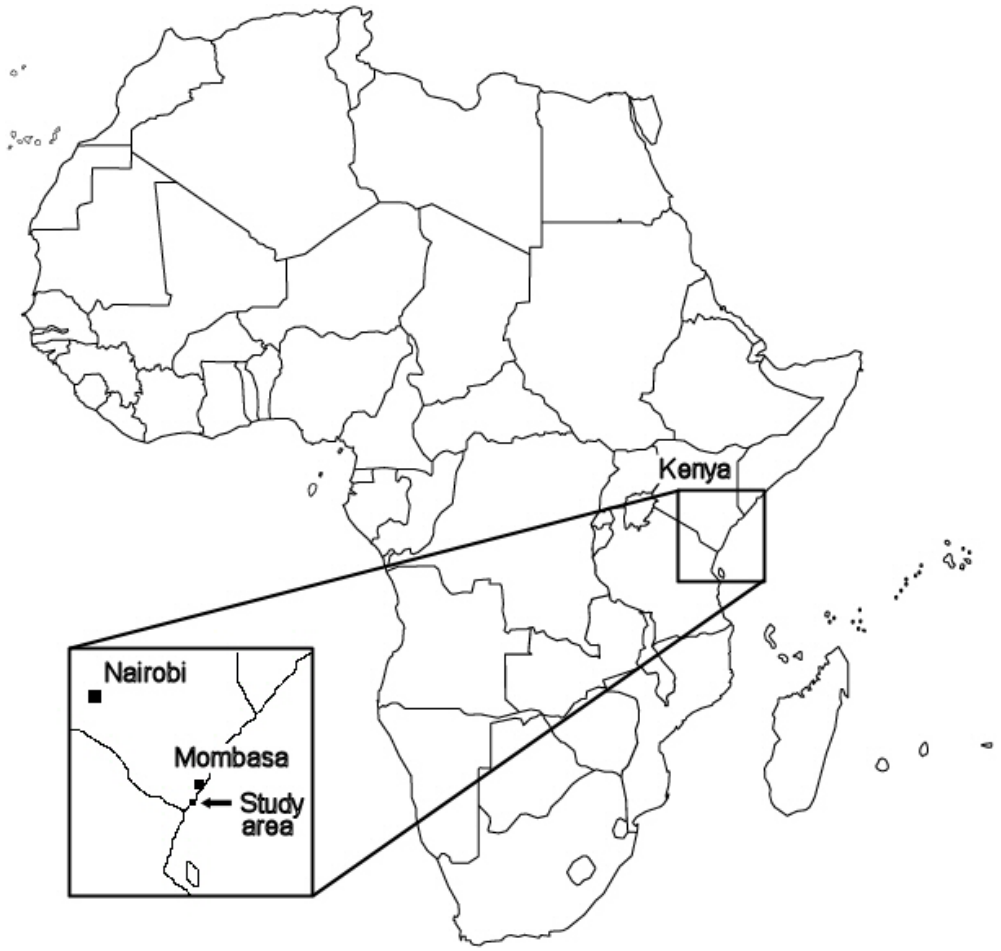

Figure 1. Map of the study area with the target community indicated in the inset of the left hand corner. The area is located on the southern Kenyan coast at 4°25'S and 39°50'E, approximately 50 km south of Mombasa.

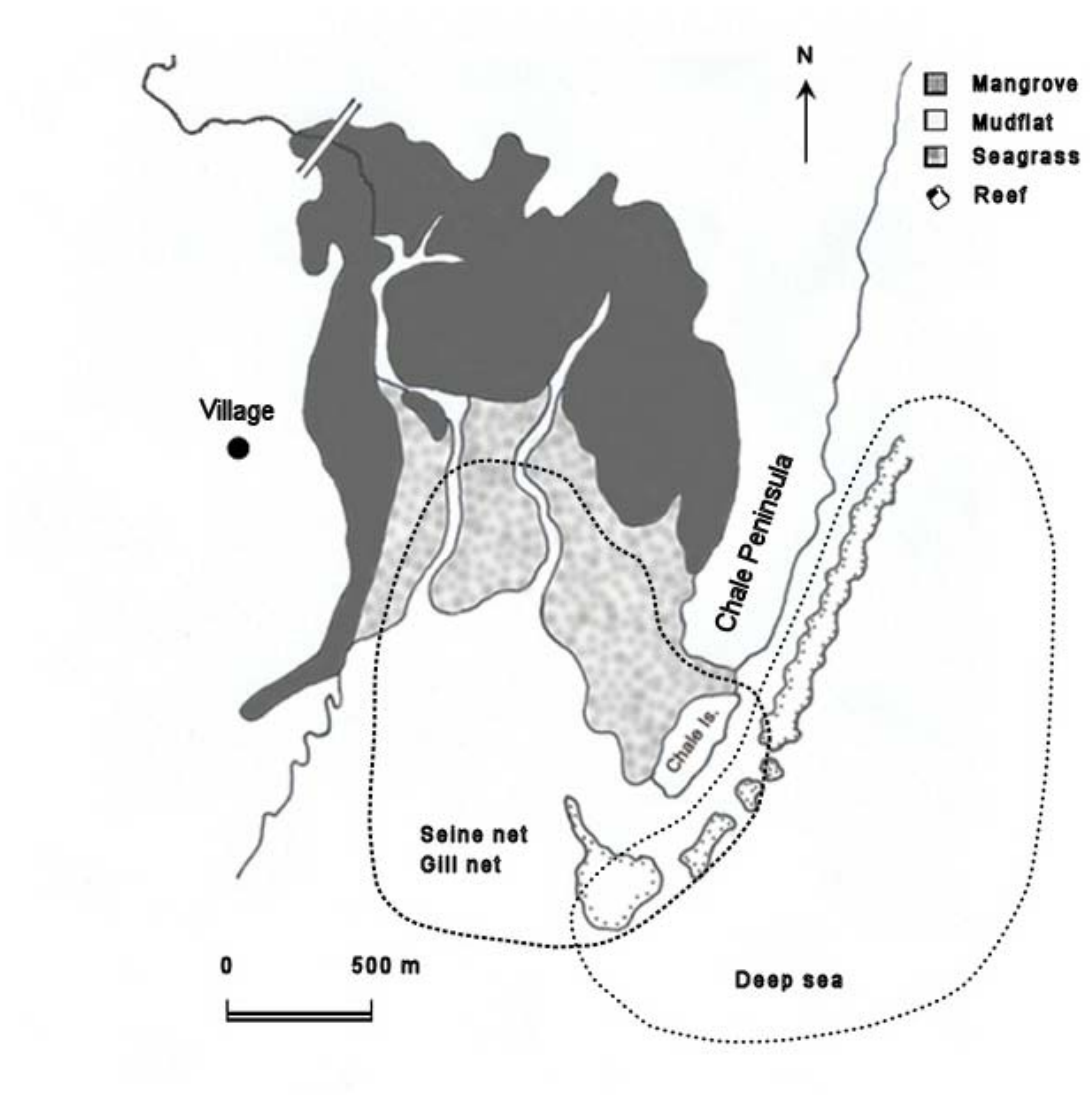

Figure 2. Map of the coastal seascape in focus. The respective distribution of mangroves, mudflats, seagrass beds and reefs is indicated. The area of primary fishing effort for each fishing related occupational category is marked with dotted lines showing the geographical distribution of fishing areas at a local scale. The occupational categories associated with each area are indicated in the figure.

resulting in approximately 1500 reported relations in total. Social network data was compiled by questionnaires completed through personal interviews with heads of households to identify social ties. Data on various types of ties was collected to investigate a number of different social networks, such as social support and gear dependency networks, etc (see Table 1). In this study, only the information/knowledge exchange network relating to the state and extraction of natural resources was used (Question 4 and 5 in Table 1). Collection of network data included both recognition and recall methods (Marsden 1990, Wasserman and Faust 1994), although only data collected using the recall method was used in this study. Recall methods involved each respondent reporting his/her relations thus generating a list of persons as well as briefly describing the relation, the type of exchange and the frequency of interaction.

Table 1 Overview of questions put to each respondent for collection of network data.

Question No	Question	Method	Type of relation
Q1	Personal information regarding age, gender, civil status etc.	-	
Q2	Do you have close family outside of #village name#? (Y/N) If yes, fill in the table below for all close family members outside of #village name#.	Recall	External social relations
Q3	With whom can you discuss important matters? (*anything important to you*) List the names in the table below.	Recall	Social support
Q4	If you noticed changes in the natural environment (e.g. the number of fish caught, the condition of the mangrove forest or reef, availability of firewood etc.), who would you discuss this with? Name persons in table below.	Recall	Information/knowledge exchange
Q5	Do you exchange information with anyone which is useful for you to carry out your common occupation? (Y/N) If yes, name persons in table below. *(For example, told you about practices, good fishing spots, equipment, timing and season etc?)*	Recall	Information/knowledge exchange
Q6	Is there any person(s) on whom you depend, or who depend on you, to carry out your (their) occupation? (Y/N) If yes, name persons in table below. *(E.g. do you need someone else's boat, gear, nets etc to carry out your occupation?)*	Recall	Gear dependency
Q7	In your occupation do you buy and/or sell your goods to anyone in particular? (Y/N) If yes, name persons in table below. *(E.g. do you sell your fish, poles, firewood, makuti etc to a particular person? Or from who do you buy bate, nets etc)* If no, see question below.	Recall	Economic exchange
Q8	Do you ever send/receive money or other valuables to/from anyone outside of the village? If yes, name person in table below.	Recall	Remittance pathways
Q9	Have you ever encountered a dispute with anyone related to your occupation? Specify why and with whom.	Recall	Conflict resolution
Q10	If you encounter a dispute with someone, do you turn to someone to settle the conflict? If yes, whom?	Recall	Conflict resolution
Q11	If you see that someone is breaking the law (within the area of your occupation) do you tell someone? If so, who?	Recall	Conflict resolution
Q12	Below is a list of ten randomly selected individuals from the village. Based on Questions 4 and 5, can you to tell us if you know them? If so do you exchange information with them and how often, on a scale (1-3)?	Recognition	Information/knowledge exchange

In addition to social relations personal attributes such as gender, age, civil status, clan, tribe, occupation and residence time in the village, among others, were collected for each respondent. All interactions with respondents were done in Kiswahili.
Data on the LEK held by different occupational categories of resource users was collected through focus groups and individual interviews and is presented in greater detail in Crona (2006). In addition to local businessmen, farmers and middlemen (fishmongers) five occupational categories of fishermen were defined based on primary gear type and fishing technique. These included Deep Sea, Seine Net, Gill Net, Handline and Speargun fishermen. Only the former three fishermen categories were used in this analysis and their group specific distribution of fishing effort in the seascape is shown in Figure 2. Detailed descriptions of occupational categories are found in Appendix 1.

In total thirteen groups were interviewed, complemented with 19 individual interviews, over a period of four months in 2004 and 2005. Each group contained between four and six participants and groups were selected based on interviews with the village chairman and

fishermen at the local landing site. In most cases a crew captain was approached and asked to participate along with members of his crew.

As one purpose of the study was to investigate and compare ecological knowledge of occupational categories a segmented sampling design was used with replication of each type of group within segments. In order to compare knowledge among groups in each segment a semi-structured interview guideline was used based on the approach described by Morgan (1998). The discussion focused on two topics 1) the knowledge of species and ecological processes in the bay and 2) acknowledgment of changes in the ecosystem over time and understanding of ecological processes and links among components in the system. Knowledge was determined as LEK, and included in the subsequent analysis, only if mentioned at least three times by individual groups (as suggested by Davis and Wagner 2003).

Analysis

Methods from the interdisciplinary field of Social Network Analysis (SNA) were used to quantitatively assess structural aspects of the social network (for overview see Wasserman and Faust 1994, Scott 2000, Freeman 2004). To investigate if fishing technique (or other occupation) is important in structuring communication networks related to natural resources we defined two kinds of groups in our analyses: (1) Groups based on respondents' occupations ("Occupational groups"), and (2) groups derived solely based on relations reported by the respondents, without taking into account individual attributes such as occupation, i.e. focusing on the structural pattern of relations only ("Relational groups"). Knowledge was treated as the dependent variable and its distribution among resource users was qualitatively compared to maps of group relations to assess if and how information/knowledge transfer could explain LEK distributions. Analysis of the knowledge, ideas and attitudes derived from focus groups were compared based on the two major knowledge topics outlined above and are described further in Crona (2006).

Occupational groups

For occupational groups, we defined group membership based on occupation and calculated the amount of within-group relations (i.e. the number of social ties between persons of the same occupation) as well as the amount of relations between members of different groups. To analyze relations between occupational groups a sociomatrix (e.g. Wasserman and Faust 1994) was constructed. The numbers of relations within and among groups are then compared to the number of relations that would be expected by chance alone, assuming all relations were distributed randomly without any regard to respondents' occupations. This resulted in a ratio of measured versus expected relations calculated using Ucinet (Borgatti et al. 2002). A ratio above 1.0 implies a higher-than-expected number of reported relations between those particular groups and values below 1.0 lower-than-expected number of reported relations. By using the hypergeometric probability function in Statistix 8 (Analytical Software, Tallahasse, FL, USA), the likelihood that a calculated ratio in the sociomatrix could have arisen by chance alone could be estimated.

We categorized the strength of an inter-group relation as *strong* if the ratio exceeded 1.0, *medium* if the ratio was between 0.5 and 1.0, and *low* if the ration was below 0.5. Groups and their relational ties where plotted using a multidimensional scaling (MDS) technique where position in space is determined by inter-group relations and their strengths (Frank 1996). Groups that have strong inter-group relations, as well as similar patterns of relations to other groups, are positioned close to each other in the MDS plot. Thus, groups that end up at the center of the plot occupy a central social position.

Relational groups

Relational groups were determined based only on relations reported by respondents. There are numerous methods available to formally divide individuals in a network into different sub-groups (Wasserman and Faust 1994, Scott 2000). All methods have emerged from a desire to distinguish subsets of individuals based on the cohesiveness or reachability of group members, as well as on the relative frequency of relations within the subset as compared to relations to non-members. We have chosen the "Community Structure" (CS) method proposed by Girvan and Newman (2002). Its major difference compared to most other available methods is that CS does not discriminate against peripheral nodes. Whereas nodes with just one link tend to be left out by other methods, CS simply assigns them the same group membership as their neighbour. Other methods are, however, generally better in finding cores of strongly and/or intensely interlinked individuals (Newman and Girvan 2004), but as our priority was to assign all individuals to appropriate groups (not only the most interconnected ones) the CS method was suitable.

The CS method produces hierarchically nested groups by incrementally dividing the population into increasingly smaller units until all individuals are assigned to separate groups. Thus, each hierarchical level produces a different set of groups, and requires the analyst to make a choice at which level the most appropriate group division occurs. We used the measure Modularity suggested by Newman and Girvan (2004) to objectively choose an appropriate hierarchical level. The chosen level represented the one at which the computed Modularity reached a maximum. The measure of Modularity can also be used as a form of significance test whereby the values of Modularity of the observed network are compared to values calculated for randomly generated networks (with the same number of nodes and links as the measured network component). This allows one to see if values of Modularity based on the former are likely to have been obtained if the observed network structure was purely random, without any tendencies for multiple groups.

Respondents and their relational ties were plotted using the same MDS technique as for occupational groups.

To check if occupational category correlated with membership of the relational groups, we applied a chi-square analysis. To account for the sparseness in our cross-tabulation of relational groups and occupational categories, we applied Monte Carlo simulations using StatXact 6 (Cytel Software Corporation, Cambridge, MA, USA) to obtain reliable p-values. StatXact 6 also provided us with adjusted standardized residuals (Haberman 1978) for each cell in the cross-tab.

RESULTS

Quantification of communication and information exchange about natural resources among individuals of the same occupational categories is presented in Table 2 along with the number of individuals of each occupation. Only occupational categories with more than three members were included in this analysis. Occupational categories that were very broadly defined and consequently too heterogeneous to be perceived as coherent categories were also excluded. After exclusions 116 individuals thus remained. Analysis shows strong tendencies for within-group communications among all occupational categories except businessmen and, to a lesser extent, farmers (Table 2). Based on the sociomatrix (Table 3), a multidimensional scaling plot (MDS) was generated to show the strength and patterns of communications between occupational categories (Figure 3). This figure presents the all encompassing pattern of communication among predefined occupational categories.

In line with our objective to test if fishing technique is important in defining the studied communication networks of this fishing community we also analyze group structures solely based on relations reported by respondents (in contrast to predefined categories in e.g. Figure 3). There were 47 individuals that did not reported any ties, nor were they ever reported by others. Of the remaining 159 individuals, 155 individuals were part of a single, large network component (i.e. a sub-network where it is possible to move between any two nodes using one or several links). This component was further analysed in search of cohesive groups using the Community Structure method (Girvan and Newman 2002) and result are shown in Figure 4. This figure shows the cohesive groups as spatially confined clusters of nodes.

To test the likelihood of obtaining the observed relational group structures purely by random we generated 100 random networks, assessed all the group structures of these networks using the CS method, and finally calculated the corresponding Modularities (Newman and Girvan 2004) (Figure 5). The calculated Modularities of the observed real-world network are

Table 2 Distribution of self-reported, within-group relations among occupational groups (Question 4 and 5 in Table 1). Size refers to the number of individuals within respective occupation, Ratio refers to the ratio of observed versus expected within-group relations (based on an assumed random distribution of all relations), Rel./Ind. refers to the total number of reported relations to individuals irrespective of their occupation, divided by the number of members within the group, and Rel./Ind. in group refers to the number of reported within-group relations divided by the number of group members. The number in parenthesis represents the probabilities (%) of acquiring a higher ratio assuming independence between the occupational categories and probability for relational ties. For example, for the within-group ratio of businessmen (0,92), the probability of acquiring a higher ratio would be 64%.

	Size	Ratio obs./exp.	Rel./Ind.	Rel./Ind. in group
Seine Net	16	6,13 (0,0%)	3,1	2,0
Businessmen	27	0,92 (64%)	0,7	0,5
Farmer	8	1,64 (46%)	0,9	0,3
Deep Sea	45	2,79 (0,0%)	3,6	2,7
Gill Net	10	9,2 (0,0%)	3,3	1,8
Middleman	10	5,11 (0,2%)	2,0	1,0
Mean value			2,5	1,4

Table 3 Occupational group sociomatrix (Information/knowledge exchange network; Table 1). Numbers in cells represent the ratio of the measured versus the expected number of relational ties.

	Seine Net	Businessmen	Farmer	Deep Sea	Gill Net	Middleman	Num of group members
Seine Net	**6,13**	0	0	1,02	0	0,29	16
Businessmen		**0,92**	0,21	0,19	0	0	27
Farmer			**1,64**	0,13	1,15	0,58	8
Deep Sea				**2,79**	1,23	0,72	45
Gill Net					**9,2**	0,46	10
Middleman						**5,11**	10

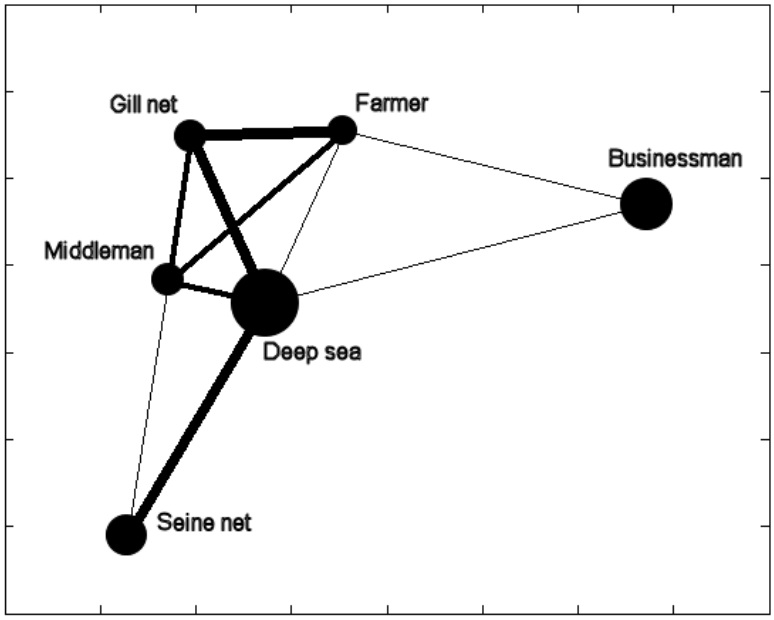

Figure 3. MDS plot showing the social network structure of relations among groups based on predefined occupational categories. The size of each node is proportional to the group size, and the thickness of the links is proportional to the strength of the inter-group relations, i.e. the ratio of the observed versus expected number of relations (thin line < 0.5, medium line < 1, thick line > 1). Worth noting is that no direct exchange between fisher categories Seine Net and Gill Net occurs.

significantly higher than would be expected for a network without multiple group tendencies. This is shown by the clearly demarked curve of Modularities for the real-world network in relation to the generated random networks (Figure 5).

Some groups have markedly lower numbers of relations within themselves and with members of other group as compared to other groups (see the periphery of Figure 4). The majority of individuals are, however, found to be assigned to groups where the density of relations both within- and between groups is relatively high. The degree of homogeneity was tested through a chi-square analysis and reveals a clear and strong tendency of homogeneity based on occupation, i.e. individuals of the same occupation occurring in the same group (Table 4).

Table 5 and 6, and Figure 6, summarize the main differences and similarities between the LEK held by the occupational categories studied. Analysis of LEK reveales discrepancies in terms of the level of detail of knowledge held by farmers and businessmen compared to the majority of resource extractor categories (Figure 6). The former occupational groups show consistently poorer knowledge of all coastal habitats as well as understanding of related ecological processes. The LEK held by fishermen of various occupational categories reveals a range, from detailed accounts of feeding of certain target species to acknowledgement of larger scale climatic changes affecting shrimp stocks and mangrove coverage. On a general level, knowledge common to most groups included the acknowledgement of the central role played by mangroves for coastal protection, nursery habitat and water quality (Table 6). The seasonal rains and related freshwater pulse affecting shrimp and fish migrations are also recognized by

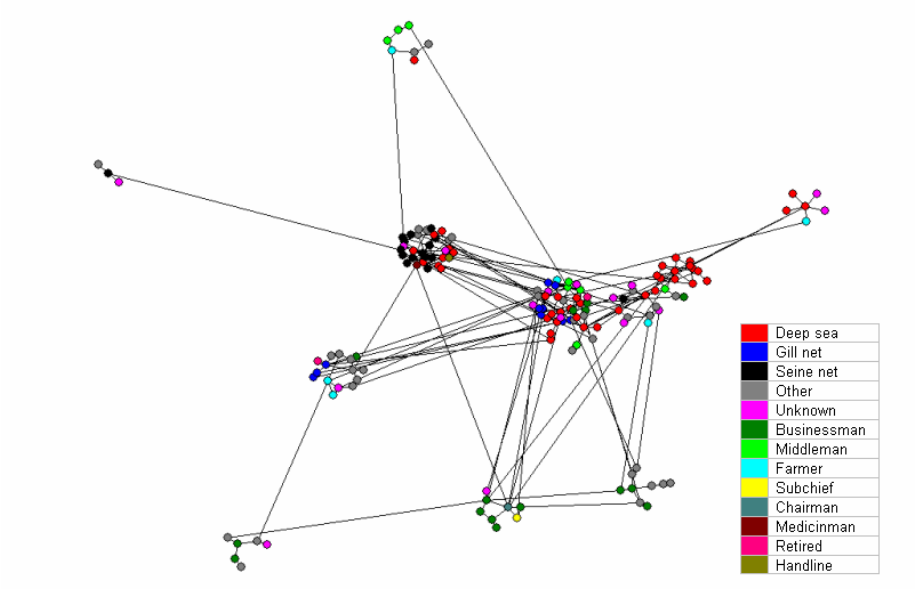

Figure 4. MDS plot of group structure based solely on relations reported by respondents. The position of each node (individual) is estimated based on both within-group relations as well as relations to other individuals outside the individual's own group. Groups are distinguishable as spatially clustered sets of nodes. Colors indicate the occupational category of each individual.

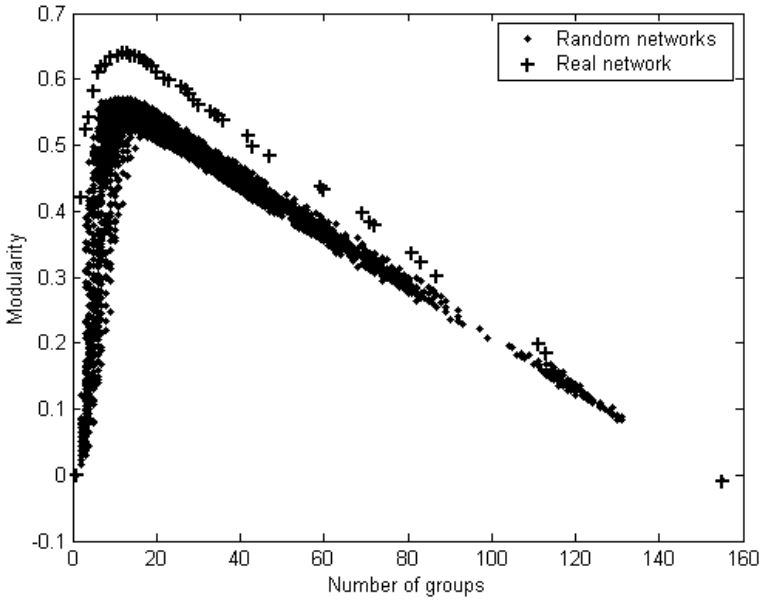

Figure 5. Values of the Modularily (Newman and Girvan 2004) plotted versus the number of groups for all hierarchical levels using the Community structure method (Newman and Girvan 2004). Dots refer to the Modularity calculated from 100 randomly generated networks with the same number of nodes and links as the observed real-world social network. Crosses represent the calculated level of Modularity for the observed network.

Table 4 Cross-table of occupational and relational groups. The values represent the count of individuals for each combination. The p-value assuming no interaction between occupation and group membership < 0.0001. Absolute values of adjusted standardized residuals ≥ 2.0 are an indication of a significant interaction between membership in the relational group and the occupational category, and are marked with a plus or a minus sign. Plus signs indicate an overrepresentation of a particular occupational category in a relation group, while the opposite applies for minus signs. O=Other, BM= Businessman, F= Farmer, MM= Middleman, GN= Gill Net fisherman, DS= Deep Sea fisherman, and S= Seine Net fisherman.

Relational Group Index	Occupational Groups							
	O	BM	F	MM	GN	DS	S	Total
1	2	0	1	0	0	3	0	6
2	2	0	1	3 (+)	0	1	0	7
3	2	0	0	0	0	0	1	3
4	8	3	1	3	7 (+)	8	0 (-)	30
5	6	3 (+)	0	0	0	0	0	9
6	9	0 (-)	0	0	0	9	14 (+)	32
7	3	5 (+)	0	0	0	0	0	8
8	9	1	2	0	3 (+)	0 (-)	0	15
9	8	0	1	0	0	3	1	13
10	4	2	0	0	0	0	0	6
11	1 (-)	1	0	1	0	12 (+)	0	15
12	4	0	0	1	0	6 (+)	0	11
Total	58	15	6	8	10	42	16	155

all categories (Table 6). Group specific knowledge includes recognition that sea urchin aggregations can affect the dynamics of seagrass meadows and associated fauna (Seine Net) and a notion of regional fish stock migrations related to wind patterns and currents (Middlemen, Deep Sea and only to some degree Seine Net fishermen). Deep Sea fishermen have knowledge of currents and linkages between the three ecosystems in Figure 6 (mangroves, seagrasses, and reefs) at a scale surpassing that of other fishing groups. In other words, they have a more holistic perception of the seascape as compared with all other groups. In addition, their notion of fish migrations span a larger geographical scale than Seine netters by including pelagic stocks moving up and down the coast (Table 5). A more detailed analysis of the LEK inventory is presented in Crona (2006).

Table 5 Summary of local ecological knowledge of different occupational groups in the target community, Kenya. Species refer to marine species of fish and shellfish targeted by categories of fishermen. For each species the functional groups to which it belongs, based on trophic level, is indicated in brackets; Pelagic/demersal predator (P), Benthic predator (BP), Herbivores (H), Planktivores (Pl), Omnivores (O)

Occupational category	**Species**	**Ecological links and processes**
Deep Sea	*Caesio* sp. (Pl) Carangidae (P) *Hyporamphus* sp. (O) *Lethrinus* sp. (BP) Scombridae (P) *Selar* sp. (P) *Siganus* sp. (H) Squid (P)	- Notion of regional fish stock migrations at a local and regional scale - Seasonal monsoon related wind patterns and currents affect fish migrations along the regional coastline - Notion among that changes in climate (timing of the monsoon rains and El Niño phenomena) have occurred recently resulting in an effect on the artisanal shrimp fishery as well as mangrove coverage - Recognition of links between the ecosystems mangroves, seagrasses and reef
Seine Net	Carangidae (P) *Caranx* sp. (P) *Lethrinus* sp. (BP) *Lutjanus argentimaculatus* (BP) Mugilidae (H) *Pomadasys* sp. (BP) Scombridae (P) *Selar* sp. (P) *Sphyraena* sp. (P) *Squid* (P) *Strongylura* sp. (P)	- Notion of regional fish stock migrations at a local scale - Seasonal monsoon related wind patterns and currents affect fish migrations along the regional coastline - Notion among that changes in climate (timing of the monsoon rains and El Niño phenomena) have occurred recently resulting in an effect on the artisanal shrimp fishery as well as mangrove coverage - Notion that sea urchin aggregations can affect the dynamics of seagrass meadows and associated fauna.
Gill Net	*Chanos chanos*(O) *Gerres* sp. *(BP)* *Lethrinus harak* (BP) Mugilidae (H, P) *Siganus* sp. (H) *Sphyraena* sp. (P) *Strongylura* sp. (P)	- Notion among that changes in climate (timing of the monsoon rains and El Niño phenomena) have occurred recently resulting in an effect on the artisanal shrimp fishery as well as mangrove coverage - Seasonal monsoon related wind patterns and currents affect fish migrations along the regional coastline
Middlemen		- Notion of regional fish stock migrations - Seasonal monsoon related wind patterns and currents affect fish migrations along the regional coastline - Recognition of interlinkages between seascape components
Farmers		Poor general knowledge of all ecological links and processes in the seascape
Businessmen		Poor general knowledge of all ecological links and processes in the seascape

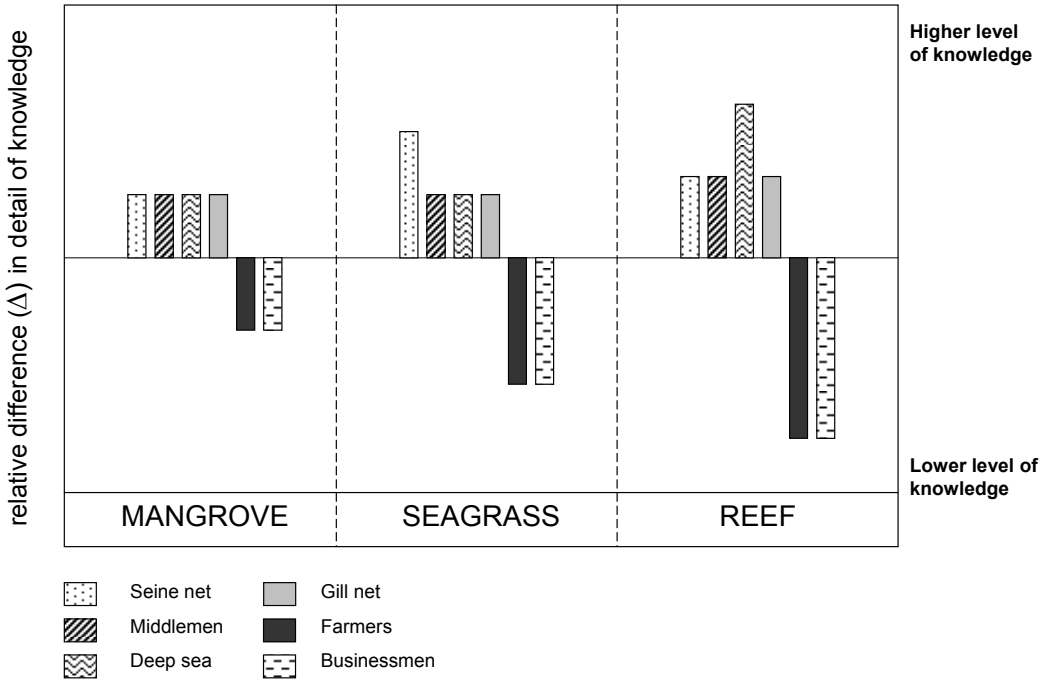

Figure 6. Relative difference in local ecological knowledge among different occupational groups operating in the target community. Knowledge is divided into three categories based on the three recognized sub-components of the coastal seascape; mangrove, seagrass and reef. Knowledge of different groups for each sub-component is represented as the relative difference of their level of knowledge compared to an estimated average level of knowledge for all groups (the baseline in the figure). Thus the bars represent each group's knowledge in relation to other groups. Amount of knowledge, for each occupational category, is ranked based on the expressed level of detail of ecological components and processes (adapted from Crona 2006).

DISCUSSION

Sticking with your own kind

Homogeneity refers to the tendency for people to have more connections to others of their own kind (whether defined by characteristics such as gender, race, social class or other attributes) than they have to others. Shared social characteristics are presumed to not only reduce conflict, but also facilitate communication due to common background and shared life experience (Reagans and McEvily 2003). Homogeneity is also a factor thought to enhance tacit knowledge transfer (Cross 2001). High levels of homogeneity could, however, reduce diversity and limit access to distant resources (Krackhardt and Stern 1988). In this study, homogeneity is observed primarily through occupational category. Both the analysis of the network structures based on predefined occupational groups (Figure 3 and Table 2 and 3), and

Table 6 Summary of local ecological knowledge common to all studied occupational groups in the target community, Kenya.

Ecological component	Ecological links and processes
Mangroves	- Knowledge of the central function of mangroves in coastal biological, hydrological and geomorphologic processes in the form of nursery habitats, water filtration and sediment stabilization
	- Awareness of the nursery function provided by mangroves for fish and shellfish residing part of their life outside of the mangrove habitat. Shows a notion of the positive spillover effect of such functions on coupled ecological subsystems such as seagrass beds and coral reefs [a]
	- Acknowledgement that historical and present land-uses, such as mangrove cutting will cause changes in the distribution and abundance of associated species (crabs, shrimp, fish) and ecosystem functions such as soil stabilization, water movement, nursery habitats, nesting areas and wind breakers[a]
Penaeidae shrimps	- Acknowledgement that seasonal climatic changes affect the distribution and abundance of shrimp and finfish in the area: Seasonal monsoons and the resulting freshwater outflow attract juvenile shrimps into the mangrove system.

[a] knowledge poor among farmers and businessmen

the analysis of the relational groups (Figure 4 and Table 4), shows that occupation is a strong determinant of group cohesion and consequently supports the former division. This indicates that gear defined occupation does play an important role in defining communication of resource related knowledge and information in this community. Glaesel (2000) similarly showed gear defined occupation to be very important for identity politics in other Kenyan fishing communities indicating that such patterns are likely a more general feature of coastal communities in the area.

LEK distribution and network structure

There is a fair agreement between the distribution and content of LEK among studied groups and the structure of the social network examined. A qualitative comparison of the network structure (Figures 3) and the content and distribution of knowledge (Table 5) shows that groups with strong links between each other, i.e. fishermen, tend to have similar knowledge. The two categories not directly involved in marine resource extraction have a much poorer understanding of associated ecological components and processes (businessmen and farmers). The weak ties of the local businessmen to coastal resource extractors may explain their lack of ecological knowledge. As they are unlikely to acquire such knowledge through direct personal experience this group is likely to remain with a poorer conception of resource status. The farmers are however more closely connected to the resource extractors (Figure 3) which may seem like a contradiction given their limited knowledge (Figure 6). This may be explained by the fact that the group is very small (only eight individuals) and consequently their relations rather few, which means that the impact of each of their reported relations becomes statistically large. This makes the estimations of the strength of their relations with other groups somewhat unreliable.

Deep Sea fishermen's more holistic perception of the seascape could be attributable to their central position in the network. To some extent they share this with the middlemen of whom some have acquired this broader seascape knowledge through personal experience but more importantly through communication with all groups of fishermen as apparent in Figure 3. Seine netters are, however, slightly more distanced from, i.e. have fewer ties to, the tight cluster formed by Middlemen, Deep Sea, and Gill net fishermen (Figure 3). It is argued that tacit or complex knowledge transfer requires frequent and intense interactions (Hansen 1999, Reagans and McEvily 2003) thus only fairly tight groups are likely to develop complex group-specific knowledge. If communication links are more diversely distributed among actors (as observed among the other fishermen categories), the possibility to maintain group-specific knowledge is reduced. In fact, Seine Net fishermen report that approximately 2 out of 3 relations are with other Seine netters (Table 2), and of those few outbound relations, most are with Deep Sea fishermen only. This can explain why certain group specific knowledge relating to linkages between seagrass variations, sea urchin abundance and fish stocks - information of a rather complex nature - is still maintained within the group of Seine netters.

While outlining this agreement between knowledge distribution and network structure we feel it is necessary to also mention the inherent problem of causality in network analysis which relates to the need for longitudinal data to verify changes in dependent variables following changes of the network structure. However, although static, the analysis presented here does in fact show a fair correlation between the two wherefore our continued discussion will focus on implications of this, regardless of causality. In addition, our data does not allow us to in detail differentiate between different sources of LEK. Therefore, we can not determine to what extent observed similarities in knowledge among different groups are caused by similar experiences or by inter-group exchange of information and knowledge. We are, however, convinced that the observed distribution of knowledge cannot be adequately explained without considering the effect of the social network structure based on the discussion above (see also Reagans and McEvily 2003 and references therein).

Prerequisites for collective action

The community in focus has not initiated any collective action to reduce fishing pressure or use of destructive gears. This is due, in part, to a lack of empowerment of the community vis à vis the government with regard to management of natural resources. However, we propose that observed network structures may also serve as an explanation. The groups most central, i.e. most centrally positioned in the network (see Figure 3 and 4), and also most knowledgeable in the village are those represented by Deep Sea fishermen, many of which are migrant fishermen returning to Tanzania during seasons of low fishing activity. The nature of the Deep Sea fishing technique, using large boats, also makes this category of fishermen less confined to the immediate seascape adjacent to the village, allowing them to target pelagic stocks that are less vulnerable to over-fishing on a local scale. Consequently, in their view, catches have not changed significantly which may have reduced their perception of the fishery as overexploited, at least in relation to their own operations (Crona 2006). Perceptions of overexploitation as a general problem were vague. This, in combination with their migrant

status reducing their sense of place, affects motivation and makes Deep Sea fishermen less likely to instigate action to regulate fishing activities. Thus, the group structurally best positioned does not take advantage of this to initiate collective action, while other groups perhaps more willing to initiate action are potentially not able to do so due to their less favorable network positions.

In addition, some occupational categories (e.g. businessmen) are poorly involved in the knowledge and information exchange regarding natural resources. Even though they could be instrumental in enabling collective action through their ties to village committees and other institutional hierarchies (cf. Krishna 2002) their lack of knowledge and access to information on resource status is likely to negatively affect their incentive to engage in collective action initiatives.

Centrality or complexity – The lack of an optimal network structure

Social networks are increasingly cited as instrumental in enabling communities to adaptively respond to environmental change and to initiate and sustain successful co-management of natural resources (Olsson 2004a, Tompkins and Adger 2004) but the precise mechanisms by which this happens are rarely discussed. Nonetheless the field of sociology is ripe with examples showing how structures of social networks are crucial for understanding and explaining social phenomena (Wasserman and Faust 1994). For example, social psychologists have shown that centralized networks, i.e. when one or just a small cluster of actors are very centrally positioned in the network leaving the others in the periphery, perform simple tasks more efficiently than decentralized ones (Leavitt 1951, Shaw 1981). However, they also showed that decentralized structures perform better when tasks are complex. This is attributed to the contribution from all members to the solution, providing diversity of information and knowledge in solving the problem. Environmental management must, in many respects, be considered a complex task, with complex chains of cause and effect in ecological systems. It is therefore likely that less centralized network structures are preferred for long-term management of ecosystems. Yet centralized structures in resource management play an important role in mobilizing and coordinating human resources for collective action (this is one argument upon which our previous discussion relies). In Kristianstad, for example, Olsson et al. (2004b) showed that in the initial phase of building consensus and amassing support for collective action around the management of the wetland, a network centered around a few highly active individuals laid the ground to what has emerged as a seemingly successful collaboration among a network of stakeholder groups in the area. These findings are in line with the effectiveness of centralized structures for coordination and dissemination of information shown by Leavitt (1951).

The inevitable conclusion is thus that different network structures have features that differently affect the social dynamics judged to be important for successful adaptive co-management. Finding one optimal network structure is unlikely as optimization of structure seems related to the phase of the management process. For example, high centralization may be beneficial during the initiation phase to coordinate and instigate collective action. Decentralization, on the other hand, may provide access to diverse sources of information from different groups which is needed for sustainable management in the long term. A

potentially fruitful path is to look at what social network structures exist within a given community and analyze structural characteristics such as tendency for multiple group formation (c.f. Figure 4). Guided by evidence on the effect these structural characteristics may have on coordination of initiatives, consensus-building, and information/knowledge transfer, management strategies can be designed which maximize the potential of a certain structure and includes elements to minimize its drawbacks.

CONCLUSION

Social networks are increasingly cited as instrumental in enabling communities to adaptively respond to environmental change and to initiate and sustain successful co-management of natural resources. Here we have started to investigate the precise mechanisms by which this may occur.

This study identifies a distinct pattern of correlation between the distribution of LEK held by resource users and the social network for communication of resource related knowledge and information. Fishermen, in spite of using different gear types and fishing in different areas, tend to have similar knowledge; a fact that may be attributed to their relatively frequent relations. On the other hand, the weak ties between fishermen and non-fishermen may be one factor explaining the latter's lack of ecological knowledge. On a more detailed level it is shown that gear defined occupation plays an important role in defining resource related communication structures indicating that fishermen are, in fact, not a homogenous stakeholder group but consist of a number of subgroups communicating primarily with members of their own occupational category. This pattern of subgroups is also qualitatively shown to correlate with variations of fishermen's LEK.

Our results demonstrate that structures in relational networks are important for identifying central and potentially influential actors. They also indicate that incentives and attributes that enable these actors to emerge as leaders and coordinate and instigate collective action are essential for successful co-management. Without the appropriate incentives and knowledge, favorably positioned actors will not exploit their positions to initiate collective action. In this study, this was exemplified by the centrally positioned group of Deep Sea fishermen who have not taken any initiatives to regulate resource extractions. As such they may, in fact, act as barriers for collective action since highly motivated but less central actors have difficulty initiating action due to less favorable positions. Furthermore, potentially influential actors, here represented by local businessmen, are loosely tied to the communication network of resource extractors. Thus, their lack of knowledge and access to information on resource status is likely to negatively affect their incentive to engage in collective action initiatives even though they could play an instrumental role through their ties to village committees and other institutional hierarchies.

Although our current study is limited to a rural village in Kenya, we believe our results are potentially applicable over a larger scale. Small fishing communities largely dependent on direct resource extraction are a common feature of many third world countries, and the

cultural setting in which they are embedded is likely to be similar at least along the Swahili section of the East African coast.

We conclude that social network analysis is a valuable tool for identifying de facto social groups, influential actors and patterns of communications but should be combined with identification of incentives and attributes that could enable potentially influential actors to emerge as leaders coordinating and instigating collective action essential for successful co-management. Moreover, even though the distribution of LEK seems related to the network structure, there is a need to further investigate how this may affect possibilities for collective action and co-management of natural resources. The formal institutional set-up, which in part discourages local initiatives, may to some extent explain the overexploitation of the fishing resources in our study area. However, we hypothesize that the lack of collective action to remedy this unsustainable situation may also be attributed to the differences in resource knowledge among the villagers, a difference seemingly correlated with the structures of the social networks in the community.

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REFERENCES

Abrahamson, E., and L. Rosenkopf. 1997. Social network effects on the extent of innovation diffusion: A computer simulation. *Organization Science* **8**(3):289-309.

Becker, C. D., and K. Ghimire. 2003. Synergy between traditional ecological knowledge and conservation science supports forest preservation in Ecuador. *Conservation Ecology* **8**(1).

Borgatti, S. P., M. G. Everett, and L. C. Freeman. 2002. *Ucinet for Windows: Software for Social Network Analysis*. Harvard: Analytic Technologies.

Buck, L. E., C. C. Geisler, J. Schelhas, and E. Wollenberg, editors. 2001. *Biological Diversity: Balancing interests through adaptive collaborative management.* CRC Press, New York.

Carlsson, L., and F. Berkes. 2005. Co-management: concepts and methodological implications. *Journal of Environmental Management* **75**:65-76.

Carpenter, S., B. Walker, J. M. Anderies, and N. Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* **4**(8):765-781.

Cooley, C. H. 1909. *On self and social organization*. The University of Chicago Press, Chicago.

Crona, B. I. 2006. Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. *Ecology and Society* **11**(1):32.

Cross, R., Borgatti, S. P. and Parker, A. 2001. Beyond answers: Dimensions of the advice network. *Social Networks* **23**(3):215-235.

Dahdouh-Guebas, F., C. Mathenge, J. G. Kairo, and N. Koedam. 2000. Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Economic Botany* **54**(4):513-527.

Davis, A., and J. R. Wagner. 2003. Who knows? On the importance of identifying 'experts' when researching local ecological knowledge. *Human Ecology* **31**(3):463-489.

Festinger, L., S. Schachter, and K. Back. 1950. *Social pressures in informal groups. A study of human factors in housing*. Harper & Brothers, New York.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C. S. Holling. 2004. Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. *Annual Review of Ecology, Evolution, and Systematics* **35**(1):557-581.

Frank, K. A. 1996. Mapping interactions within and between cohesive subgroups. *Social Networks* **18**(2):93-119.

Freeman, L. C. 2004. *The development of social network analysis - A study in the sociology of science*. Empirical Press, Vancouver.

Gadgil, M., P. R. S. Rao, G. Utkarsh, P. Pramod, and A. Chhatre. 2000. New meanings for old knowledge: The People's Biodiversity Registers program. *Ecological Applications* **10**(5):1307-1317.

Ghimire, S. K., D. McKey, and Y. Aumeeruddy-Thomas. 2004. Heterogeneity in Ethnoecological knowledge and management of medicinal plants in the Himalayas of Nepal: Implications for conservation. *Ecology and Society* **9**(3).

Girvan, M., and M. E. J. Newman. 2002. Community structure in social and biological networks. *Proceedings of the National Academy of Sciences of the United States of America* **99**(12):7821-7826.

Glaesel, H. 2000. State and local resistance to the exapnsion of two environmentally harmful marine fishing techniques in Kenya. *Society and Natural Resources* **13**:321-338.

Gould, R. V., and R. M. Fernandez. 1989. Structure of mediation: a formal approach to brokerage in transactions networks. *Sociological Methodology* **19**:89-126.

Granovetter, M. 1973. The strength of weak ties. *American Journal of Sociology* **76**(6):1360-1380.

Haberman, S. J. 1978. *Analysis of quantitative data: Vol 1 Introductionary topics*. Academic Press, New York.

Hansen, M. T. 1999. The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly* **44**:82-111.

Holling, C. S. 1978. *Adaptive environmental assessment and management*. John Wiley & Sons, New York.

Homans, G. C. 1950. *The Human Group*. Routledge & Kegan Paul Ltd, London.

Hunn, E. S., D. R. Johnson, P. N. Russel, and T. F. Thornton. 2003. Huna Tinglit traditional environmental knowledge, conservation, and the management of a 'wilderness' park. *Current Anthropology* **44**(Supplement):S79-S103.

Johannes, R. E. 1981. *Word of the lagoon: Fishing and marine lore in the Palau district of Micronesia.* University of California Press, London.

Johannes, R. E. 1998. The case for data-less marine resource management: examples from tropical nearshore fisheries. *Trends in Ecology and Evolution* **13**:243-246.

Kadushin, C. 1966. The friends and supporters of Psychotherapy: on social circles in urban life. *American Sociological Review* **31**:786-802.

Krackhardt, D., and R. N. Stern. 1988. Informal networks and organizational crisis- An experimental simulation. *Social Psychology Quarterly* **51**(2):123-140.

Krishna, A. 2002. *Active Social Capital - Tracing the roots of development and democracy*. Columbia University Press, New York.

Leavitt, H. 1951. Some effects of certain communication patterns on group performance. *Journal of Abnormal and Social Psychology* **46**:38-50.

Marsden, P. V. 1990. Network Data and Measurement. *Annual Review of Sociology* **16**:435-463.

McClanahan, T. R., H. Glaesel, J. Rubens, and R. Kiambo. 1997. The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. *Environmental Conservation* **24**(2):105-120.

Moller, H., F. Berkes, P. O'Brian Lyver, and M. Kislalioglu. 2004. Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society* **9**(3).

Morgan, D. L. 1998. *Planning Focus Groups*. Sage Publications Inc., London.

Newman, M. E. J., and M. Girvan. 2004. Finding and evaluating community structure in networks. *Physical Review E* **69**(2).

Nygren, A. 2005. Community-based forest management within the context of institutional decentralization in Honduras. *World Development* **33**(4):639-655.

Obura, D. O., I. N. Wanyoni, and J. M. Mwaura. 2002. Participatory monitoring of an artisanal fishery in Kenya. in O. Lindén, D. Souter, D. Wilhelmsson, and D. Obura, editors. *Coral Reef Degradation in the Indian Ocean, Status Report 2002*. Cordio, University of Kalmar, Sweden.

Ochiewo, J. 2004. Changing fisheries practices and their social implications in south coast Kenya. *Ocean & Coastal Management* **47**:389-408.

Olsson, P., C. Folke. and F. Berkes. 2004a. Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management* **34**(1):75-90.

Olsson, P., C. Folke, and T. Hahn. 2004b. Social-ecological transformation for ecosystem management: The development of adaptive co -management of a wetland landscape in southern Sweden. *Ecology and Society* **9**(4).

Ostrom, E. 2005. *Understanding Institutional Diversity*. Princeton University Press, Bloomington.

Reagans, R., and B. McEvily. 2003. Network structure and knowledge transfer: The effects of cohesion and range. *Administrative Science Quarterly* **48**(2):240-267.

Scheffer, M., S. Carpenter, J. A. Foley, C. Folke, and B. Walker. 2001. Catastrophic shifts in ecosystems. *Nature* **413**:591-596.

Schneider, M., J. Scholz, M. Lubell, D. Mindruta, and M. Edwardsen. 2003. Building Consensual Institutions: Networks and the National Estuary Program. *American Journal of Political Science* **47**(1):143-158.

Scott, J. 2000. *Social Network Analysis. A handbook.* 2 edition. Sage Publications, London.

Shaw, M. E. 1981. *Group dynamics : the psychology of small group behavior* 3 edition. McGraw-Hill, New York.

Tompkins, E. L., and W. N. Adger. 2004. Does adaptive management of natural resources enhance resilience to climatic change? *Ecology and Society* **9**(2).

Walker, B., S. Carpenter, J. M. Anderies, N. Abel, G. Cumming, M. A. Janssen, L. Lebel, J. Norberg, G. Peterson, and R. Pritchard. 2002. Resilience Management in Social-ecological Systems: a Working Hypothesis for a Participatory Approach. *Conservation Ecology* **6**(1).

Wasserman, S., and K. Faust. 1994. *Social Network Analysis - Methods and applications*. Cambride University Press, Cambridge.

Weimann, G. 1982. On the importance of marginality: One more step into the two-step flow of communication. *American Sociological Review* **47**(6):764-773.

APPENDIX 1: Data collection Local Ecological Knowledge (LEK)

Seven different occupational categories were identified; businessmen (local entrepreneurs), middlemen and five occupational categories of fishermen defined based on primary gear type and fishing technique. Businessmen is a rather broad occupational category, which was defined based on a description by respondents of their livelihood as selling and/or buying any kind of goods such as food, groceries, building material and related services. Middlemen is the local term used for fishmongers, persons who buy fish from the fishermen directly at the landing sites and sell it on to a third party. Because their business is purely focused on fish they were distinguished from other businessmen. Those respondents who did not qualify into any of the above categories were classified as "Others". This category included basically all activities that did not sort under the above mentioned categories and ranged from driving local taxis and commuting buses to washing clothes or doing temporary construction work. This division was based on the assumption that people trading services are likely to be more decoupled from the natural resource base. A small number of categories were represented by only one individual but were judged to be sufficiently influential in the community and thus distinguished (e.g. medicine man, chairman, sub-chief). The category "Unknown" included individuals that were either not interviewed, retired or could not be classified.

A semi-structured interview guideline was used based on the approach described by Morgan (1998) and is presented below.

Interview guideline

Introduction

Q: Let me ask, are you all from #village name#? (Respondents were asked to state their names, where they live, and for how long)
Q: How long have you been fishing (farming, doing business etc) in this area?
Q: Could you tell me a little about how and why each of you became a fisherman? (The question was asked to give a brief personal history of each group member)
Depending on the answers this was followed up with…
Q: Is that a common way of entering the profession?
Q: Does this mean that your sons/children will become fishermen as well? (The question was asked to give an indication of a potential changes in traditions, knowledge transfer and young people moving from village)
Q: How will all the knowledge you have be passed on to younger generations?
Q: Do you feel confident that the knowledge will be kept this way?
Q: Is it important that such knowledge is maintained and passed on to younger generations?

Topic 1- Knowledge of species and ecological processes in the bay

Q: Did you get a good catch today? What did you catch?
Q: Do you always catch this type of fish? If not what else do you normally catch? (A discussion around a representative composition of catch in terms of different species)
Q: Respondents were asked to identify the 10-15 most important fish species they catch taking into consideration the anticipated price at sale, the perceived abundance and the proportional importance of the species to their daily catch.

Q: Out of these 10-15, which 5 species do you judge to be the most important (based on anticipated price at sale, the perceived abundance and the proportional importance of the species to their daily catch)?
Q: Could you explain to me how the catch changes over the course of the year, from season to season, fort each of these five taxa/species?
Q: For each of the 5 taxa/species:

- Where do you catch it? At what time/season? Why?
- Are they adults?
- What about when they are young, where can you find them? Why?
- What do these fish eat at different stages of their life?

At this point the group was asked to draw a rough map of the area together with the interviewer. Specific sites and characteristic features on the map were discussed to ensure that the interviewer's perception of the area map agreed with the one held by the group. All group members were encouraged to get involved in the process. The map was then used to indicate primary target areas for the taxa/species identified in the previous questions.

Q: Do you use any bate when fishing? Where does it come from and how/why?
Q: Respondents were asked to identify 3 taxa/species of fish that they associate primarily with A) mangroves B) sea grass beds C) reefs.
(This question was used partly as a validation tool for knowledge of target species above but also as a measure of the how easily respondents of non-fisher categories could differentiate between fish taxa associated with different sub-systems of the coastal seascape)

Throughout the above discussion respondents were probed for clarifications and further explanations wherever appropriate and needed.

Shrimps
Q: Do shrimps come in the mangroves?
Q: If so why are they found in the mangroves?
Q: Are they big or small when they come in?
Q: Where (in the bay) are shrimps caught? Why?

Crabs
Q: Where do they live? And why?
Q: Do they live their whole life there? Explain. (The question was asked to reveal knowledge of the crab life cycle).

Q: What do you think would happen if most of the mangroves around the bay were cut down? Would it have any effect on the fisheries? If so, how? Do you know of any other effects of mangrove deforestation?

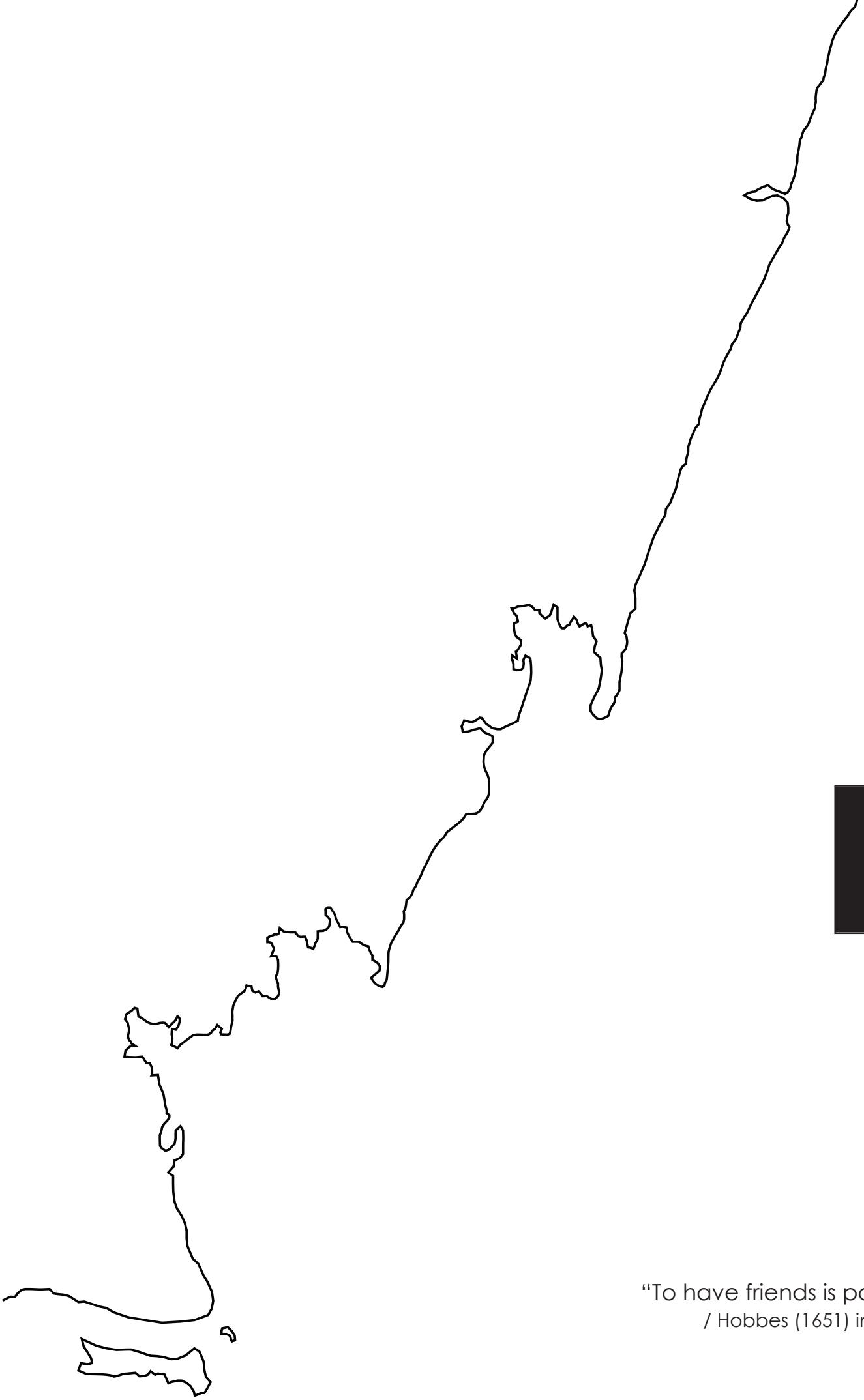
Topic 2- Acknowledgment of changes in the ecosystem over time and understanding of ecological processes and links among components in the system
Q: You say you have been fishing in the area for X years, have you noticed any changes in the type of fish/shrimps/crabs you catch or the area where fish/shrimp/crabs are caught?

Using of the map drawn previously to explain changes and patterns the following questions were asked:
Q: Have you perceived any change in mangrove coverage over the years? A discussion about coverage before, during and after the change (historical events were used to place the change in time). Respondents were asked to explain the process of change by drawing a time line indicating patterns of increasing and decreasing coverage over time.
Q: Have you perceived any change in catches over the years? Respondents were asked to identify any changes in fish catches over time by drawing a time line (with assistance from the interviewer and moderator) and indicating patterns of increasing and decreasing catches over time.
Q: Can you tell me what you think may be the reason for this change?
Q: What solutions/actions can you suggest to improve the situation? (This was asked in order to further identify coupled social-ecological knowledge and ideas, i.e. recognition of institutional/organizational change needed for resource management)

Throughout the above discussion specific questions to follow up issues of importance were incorporated under each topic.

LITTERATURE CITED

Morgan, D. L. 1998. *Planning Focus Groups*. Sage Publications Inc., London.



V

"To have friends is power"

/ Hobbes (1651) in Leviathan

Management of natural resources at the community level – exploring the role of social capital and leadership in a rural fishing community

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ABSTRACT

Social capital and leadership are important factors affecting natural resource management. This study explores aspects of social capital and leadership in a rural fishing community to seek explanations for why collective action for resource regulation has not occurred despite declining fisheries. It does so in an attempt to further operationalize the link between social capital, leadership and agency in natural resource management research. Social capital is assessed at the community level and influential individuals identified, all based on analysis of patterns of social relations among resource users.

Results show relatively high levels of social capital as quantified through social network analysis, but low willingness to report rule-breaking. Identified key individuals possessed links to several external agencies although links to financial institutions and markets beyond the trade of fishing-gear were in minority. Links to external agencies is crucial for leaders to enable communities to make use of their social capital. Consequently, identified shortcomings may, individually or in combination, explain lack of common initiatives in the village to deal with the overexploitation of fisheries. However, additional hypothesis are also put forth. First, the composition of the identified key individuals, in terms of ethnicity and occupations, was not representative of the general community. This may have lead to the low levels of problem internalization and recognition of changing ecological conditions exhibited by these key persons. Secondly, structural characteristics of the social network among key individuals reveal one person to occupy a very central position. The ability of the community to collectively organize is thus, for good or bad, largely dependent on one very central actor.

We conclude that studying structural characteristics of social networks provides for less context-dependency, thus facilitating comparisons across cases worldwide. This is crucial in researching general aspects of social capital, and agency, and their roles in natural resource management at the community level.

KEY WORDS: *social capital, social networks, natural resource management, collective action, agency, East Africa, fisheries, influential actors*

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INTRODUCTION

Social capital is often suggested as having a beneficial effect on the capacity of individuals to organize themselves effectively (Coleman 1990, Fukuyama 1995) and is, together with leadership, often seen as crucial for the initiation and maintenance of environmental conservation and management at the community level (Pretty 2003, Olsson 2004, Pretty and Smith 2004). In this study, we explore aspects of social capital and leadership in a rural fishing community to seek explanations for why collective action for sustainable management has not occurred despite strong indications of declining fisheries and inshore habitat degradation (McClanahan et al. 1997, Ochiewo 2004, Crona 2006). Focus is on natural resource management (NRM) at the community level. Thus, this study encompasses concepts such as co-management (see overview in Carlsson and Berkes 2005) and adaptive co-management (Gadgil et al. 2000, Olsson 2003) often put forth as instrumental in enabling sustainable NRM.

Extensively cited as important for reasons mentioned above, the concept of social capital and its defining characteristics is, however, not devoid of contradictions (for review see e.g. Lin 1999, Woolcock and Narayan 2000, Krishna 2002). First, the unit of analysis can vary from the individual to the group (Borgatti et al. 1998, Portes 1998). For example, Burt (2004) argues that linkages to different groups may enhance an individual's social capital, whereas Putnam (1993) discusses social capital at the scale of whole nations. Secondly, there is a lack of agreement of what actually constitutes social capital. For example, Putnam (1993) defines social capital as "features of social organization such as networks, norms and social trust that facilitate coordination and cooperation for mutual benefit". Others suggest social capital can be defined as "resources embedded in a social structure which are accessed and/or mobilized in purposive actions" (Lin 1999), thus leaving out collective assets such as trust and norms (although acknowledging that e.g. trust may promote social relations and vice versa).

Finally, social capital has been criticized for its lack of explanatory power, and several theses exist differing primarily in their view of social capital as either an exogenous or an endogenous variable. It is seen by critics as a result of institutional performance rather than its cause, where independence can not be verified. Adherents of this approach, represented by several disciplines (North 1990, Wade 1994, Schneider et al. 1997), argue for reversed causality such that the existence of institutions explains social capital. An intermediate position is taken by Krishna (2002), Berman (1997), Dale and Onyx (2005), among others, who argue that social capital has some explanatory potential but that other factors also contribute to institutional performance and collective action. One such factor is agency which is realized through the existence of agents, i.e. leaders or influential actors, who activate a potentially latent stock of social capital and use it to produce a flow of benefits. In his extensive study in rural India, Krishna (2002) found that the existence of such leaders to mediate agency was necessary to activate the stock of social capital and make it productive in terms of economic development, community harmony and democratic participation. Similarly, others have shown the importance of leaders and sense-makers for successful NRM and the effect of good leadership in this context is an expanding field of research (e.g. Westley and Vredenburg 1997, Olsson 2003).

Inspired by these findings, this study looks at the issue of social capital, agency and collective action, by applying an approach similar to Krishna (2002), although modified to fit an East African natural resource management context. We substitute development (as defined by Krishna 2002) with the ability of the community to initiate action for sustainable management of natural resources in light of overfishing and resource depletion. Agency is approached from a social network perspective by using structural network measures to identify influential actors, based on the assumption that such measures offer a robust way of identifying these influential individuals in a community (for review see e.g. Wasserman and Faust 1994). Social capital is also approached from a social network perspective. Thus we adhere to the large stream of scholars using network measures to assess social capital (see e.g. Borgatti and Foster 2003). Furthermore, mechanisms for conflict resolution and monitoring are often suggested as essential prerequisites for common property resource management (Ostrom 1990) yet rarely are these included in empirical studies of social capital. Here we incorporate these into our assessment of community social capital, thereby combining the network approach (Borgatti et al. 1998, Lin 1999) with the view of social capital as also consisting of norms facilitating coordination and cooperation (Putnam 2000).

The paper has three primary aims; (1) To assess selected aspects of community social capital, as outlined above, (2) To identify potentially influential actors, and (3) To assess if (lack of) community social capital and important leadership characteristics, individually or in combination, may explain lack of collective action. We analyze our results in relation to the community's lack of collective action with respect to regulation of natural resource extraction. The paper should be seen as an attempt to further operationalize the link between social capital, leadership and agency in NRM research and the study is one of few to empirically quantify aspects of social capital, utilizing social network analysis, in a NRM context.

METHODS

Study area

The area of focus in this study is a rural fishing village located approximately 50 km south of Mombasa in Kenya (Figure 1), and is further described in Crona and Bodin (In press). It has approximately 200 households and an estimated 1000 inhabitants. The use of resources in the village is centered around fishing and to some degree the use of mangroves for poles and firewood. A majority of the households depend primarily on fishing for their income while farming and small scale businesses represent some alternative livelihoods. Fishermen are, however, not a homogeneous group, but are grouped primarily based on gear type (Crona and Bodin In press). In spite of high levels of resource dependence, villagers have not been successful in regulating the inshore local fishery which has led to a system currently diagnosed as overexploited (McClanahan et al. 1997, Ochiewo 2004).

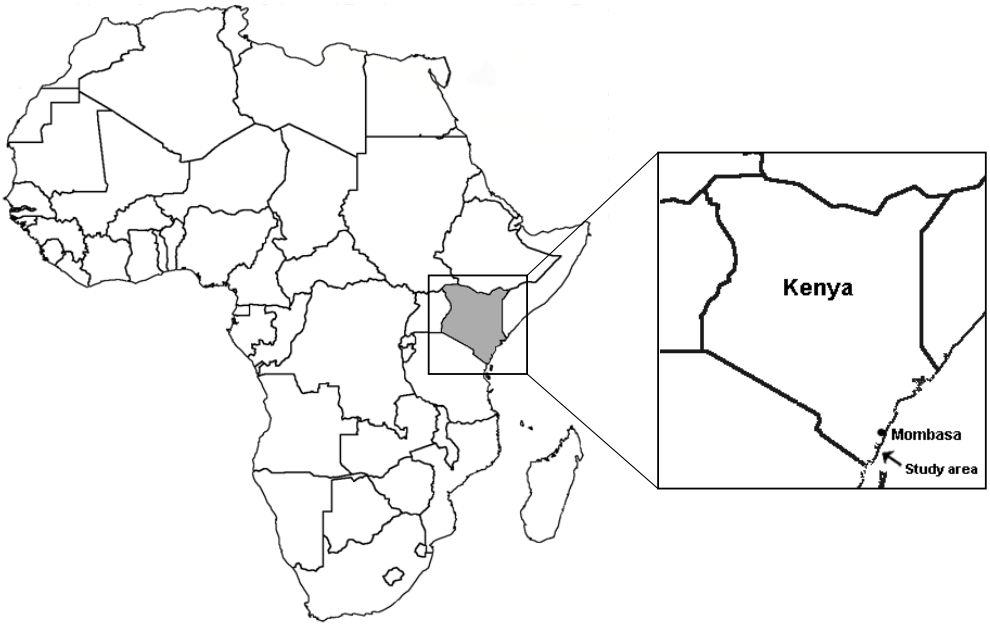

Figure 1. Map of the study area with the target community indicated in the right hand corner of the inset. The area is located on the southern Kenyan coast at 4°25'S and 39°50'E, approximately 50 km south of Mombasa.

The population of coastal Kenya is comprised of two main ethnic groups; the Mijikenda of Bantu origin and the Swahili who are of mixed Bantu, Asian and Arabic descent (King 2000). The Mijikenda comprise nine tribes, of which Digo is the predominant ethnicity of inhabitants in the study area. However, other coastal tribes such as Bajuni, historically associated with the Lamu region of the north coast, have migrated south and are present in the studied community. Many Bajuni families have traditionally been involved in mangrove cutting and trading, as well as fishing, accumulating substantial wealth, while the Mijikenda were primarily farmers but in the last century have diversified their livelihoods to include fisheries, which now constitute a substantial portion of incomes (King 2000).

Methodological approach

We assessed social capital at the level of the whole village, which we hereafter denote as the community social capital. Community social capital is assessed by: (1) quantifying some important characteristics of the community's social networks (Borgatti et al. 1998) (2) evaluating mechanisms in use for conflict resolution and (3) evaluating villagers' attitudes towards self-monitoring and reporting. Thus, we adhere to the definitions of social capital by Putnam (2000) by including both networks and aspects of norms in our assessment. As evident, we base a significant part of the measures of social capital on the community's ability to solve conflicts and willingness to impose self-monitoring and sanctions. We did so as our

focus is on aspects of social capital enhancing the ability for self-regulation of natural resource extraction, and both monitoring and the ability for conflict resolution has been shown to be crucially important for successful management of common-pool resources (Ostrom 1990). The ability to solve conflicts may be viewed as an outcome of, rather than, social capital itself (c.f. Fukuyama 1995, Putnam 2000), however, as our focus was to assess the level of social capital, we did not differentiate between causes and consequences.

Structural network measures were used to identify the most influential individuals of the community (hereafter referred to as key individuals). Assessment of the key individuals' characteristics, and their relation to agency is based primarily on interview data generated using a modified version of Krishna's questionnaires (2002) to fit the cultural context of an East African fishing community. All interactions with respondents were done in Kiswahili. Below follows a detailed description of the different approaches and their respective relation to agency and social capital.

Assessment of community social capital

Social networks

The network measures used are related to the cohesiveness of the community, the degree of fragmentation, and the ratio of bonding and bridging relations of the community's social networks. Cohesiveness is measured using the density of relations. Level of fragmentation is measured by the number of isolated subnets (i.e. network components), indicating to which degree the community is divided into isolated subgroups. The ratio of relations which falls within versus between different subgroups (Crona and Bodin In press) is also assessed. Relations within and between subgroups will from hereon be referred to as bonding and bridging ties and captures the idea of bonding and bridging social capital. These measures and their relevance in assessing the social capital are further described in Table 1. The network under study was a combination of the social support network and the (environmental) knowledge network (Table 2). In the combined support and knowledge network, relations were based on the existence of ties in either or both of the social support network and the knowledge network. Network raw data was gathered during data collection for a previous study (Crona and Bodin In press) but has not been previously analysed for this purpose.

Conflict resolution and monitoring

The institutions in place for conflict resolution were examined by measuring the extent to which villagers identify and utilize common conflict resolution mechanisms. We presented each villager with a hypothetical scenario in which they encountered a conflict which they could not resolve themselves. We then asked if, and to whom, they would turn for help in resolving the issue. Furthermore, we measured villagers' willingness to monitor and, in case of rule breaking, report others. More specifically we presented each villager with a hypothetical scenario in which they observed someone breaking a recognized rule such as e.g. fishing regulations. We then asked if, and to whom, they would report this. These behavioural characteristics could be interpreted as an indication of their respect for common rules and practices as well as the sense of community expressed by villagers. We acknowledge that cultural differences between researchers and respondents may affect interpretation of the

Table 1 Network measures with descriptions and comments on their relevance in assessing the social capital of groups of individuals.

Network measure	Description	Relation to social capital
Density or Average links per node	Network density is formally defined as the number of actual ties divided by the number of potential ties in a network. However, in this study we used the related metric of average number of ties per individual for ease of comparison with other studies.	The number of links among the villagers indicates the overall level of cohesiveness in the community, and their capability of acting in common (Granovetter 1973, Coleman 1990). In general, the more relations the better in regards to the social capital, although there may be an upper limit from where an increasing number of relations lead to excessive homogenization (cf. Oh et al. 2004, Bodin and Norberg 2005).
Number of components	A measure of the extent to which the network is divided into separate sub-networks (i.e. degree of fragmentation).	Indicates to which degree the community is divided into separate (non-overlapping) sub-groups. Distances between members in different components are thus infinite. We were particularly interested in the number of isolates (single-node components, i.e. unconnected villagers) as well as the size of the largest component.
Ratio between within- group ties and outgoing ties among groups	The ratio between the number of ties among members of the same subgroup and the number of ties between members of different subgroups in a given component.	Captures the idea of bonding vs. bridging social capital (Woolcock 2001, Pretty and Smith 2004). Bonding ties are ties within subgroups of villagers which may maintain a high level of intimacy and trust (cf. McPherson et al. 2001), while bridging ties are relations between members of different such subgroups. Both kinds of ties are important in enhancing a community's social capital (Granovetter 1973, Ancona 1990, Volker and Flap 2001).

questions asked, as well as respondents' replies. However, the authors have years of experience working in the case community and in Kenya wherefore this is not judged to have had any significant bearing on the results.

Leadership

The first step in assessing agency and leadership was to identify the most influential individuals in the community. We chose to call them key individuals, instead of leaders, as the concept of leaders includes aspects other than merely the potential for being influential.

Identification of key individuals

Key individuals were identified based on their structural positions in the community social networks. The following points motivate this approach:

Table 2 Types of social networks used in this study and their assigned names. In addition, the metrics used to construct the criteria used to identify key individuals in each type of network are presented. The network raw data was gathered during data collection for a previous study (Crona and Bodin In press).

Network name	**Type of network**	**Metric applied**
Social support network	Discussion of important matters	
Knowledge network	Exchange of information and knowledge regarding natural resources	
Combined support and knowledge network	Network generated from a combination of ties in either/both Social support network and Knowledge network	Degree-, betweenness-, and eigenvector centrality
Gear dependency network	Dependency network, i.e. who are respondents dependent upon to carry out their occupation (e.g. lease of fishing equipment).	Degree centrality
Trade network	Business network, i.e. with whom do respondents trade (buy and sell) their products/catches	Degree centrality

1) The possibility for social influence and leadership is closely tied to a person's structural position in a network (e.g. Wasserman and Faust 1994). Hence, by identifying key individuals based on their structural position, we were able to select the potentially most influential individuals.

2) By using the structural criteria, we were not dependent on a few experts' perceptions of who the most influential individuals are (Davis and Wagner 2003), nor were we limited to relying only on formal (authorized) leaders, but could focus on the key individuals that were indirectly pointed out by the community through the network structure.

We identified key individuals based on their centrality in the different social networks (Table 2). Numerous studies agree that influence is closely related to centrality, although the connection is not unambiguous (Degenne and Forsé 1999). However, a range of centrality measures, all with their specific relation to influence and possibility for leadership, are available. As we did not want to determine key individuals based on a single, narrow criterion, we chose to apply several network metrics. In all, we used five different criteria (Table 2). We used degree centrality (see e.g. Wasserman and Faust 1994), betweenness centrality (Freeman 1979) and Eigenvector centrality (Bonacich 1972) for the combined social support and knowledge network (Table 2). Thus we were able to account for three important, but separate, types of centrality for that specific network. Only degree centrality was applied to the Gear dependency and Trade networks. The reason for this is that a greater number of ties can be beneficial for an actor in these two types of networks while measuring degrees of betweenness and eigenvector centrality makes less intuitive sense in networks of dependency and commodity trading.

We identified key individuals by assigning each villager scores according to their rank for each of the five positional criteria. We limited the number of key individuals to ten. These individuals were the top ten villagers ranked (in descending order of importance) according to 1) number of times they scored highest in any of the criteria, 2) number of times they occurred

on the top ten list in any of the criteria, and finally 3) their total number of scores for all criteria. Although ten was an arbitrarily chosen number, these selected individuals represent 5% of village heads of households and, due to their limited number, can be assumed to significantly differ from an average villager in terms of influence.

In addition, our analysis also included two formally appointed leaders who were not part of the ten ranked key individuals; the village sub-chief and the chairman of the beach committee. The village sub-chief is assigned by the government and represents the highest level of formal authority in the village, and the lowermost, grass-root level of government. The beach chairman is head of an elected committee of fishermen which is a "semi-formal" body to which fishermen are expected to turn regarding fisheries-related issues.

Finally, by extracting the identified ten key individuals and the two formal leaders from the combined support and knowledge network (Table 2), we created a separate network (only consisting of these individuals) in order to estimate their level of internal communication (Figure 3).

Key individual characteristics

Methods presented above are primarily concerned with extracting and analysing quantitative data gathered from the whole community. To collect more detailed qualitatively data from identified key individuals, semi-structured interviews were conducted (Appendix 1). All ten key individuals, as well as the two formal leaders; the village sub-chief and the chairman for the beach committee, were individually interviewed. They were asked about their perception of the state of the local fishery, fish populations and nearby mangroves. They were also asked about their opinion on the community's ability to manage their resources provided they were given the appropriate authority. Their recognition of formal- and informal village leaders and institutions, as well as conflict-resolution mechanisms, was also inquired about. Finally, they were asked about their personal connections with higher-level authorities, markets/suppliers, non-governmental organizations etc. (see further in Appendix 1) and their willingness to utilize these on behalf of other members of the community. Basic attribute data (gathered previously, see Crona and Bodin In press) such as age, level of education, tribe and occupation of key individuals were also compared to the rest of the community in order to assess to what extent they represent the whole diversity of the community, but also to identify common attributes.

RESULTS

Assessing community social capital

Social networks

In analysing the network data previously gathered (Crona and Bodin In press), we found that the 172 respondents, constituting 83% of the village's entire population of households heads, reported 634 ties concerning discussion of important matters and/or exchange of information/knowledge regarding natural resources (social support network and knowledge network respectively). This corresponds to an average of 3.7 ties per person. Thirteen villagers

reported that they did not have any such ties with anyone. Two villagers were confined to a separate subnet (i.e. a component), and the remaining 157 villagers were confined to a single large component. For the social support network alone, the average number of ties per person is 1.3.

An estimate of the ratio of bonding (ties within subgroups) and bridging ties (ties between members of different subgroups) are presented in Table 3. Coherent with results from previous analysis of the knowledge network (Crona and Bodin In press), we defined the subgroups based on the respondents' occupation (Table 3). Only occupations with more than three members are included in this analysis. Occupations that were very broadly defined and consequently too heterogeneous to be perceived as coherent categories were also excluded. After exclusions 116 individuals thus remained (see further details in Crona and Bodin In press). Except for the small group of farmers, bonding ties exceed 50% for all groups. The highest fraction is, however, limited to 75%, which indicates that a significant share of villagers' relations are indeed with others of a different subgroup.

Conflict resolution and monitoring

Of the 172 interviewed villagers, only 11 did not report any trusted third party they would contact in case of being in conflict and not being able to solve it. Of all the reported third parties (i.e. persons), we present the five most cited ones in Table 4. The most cited person, the elected village chairman, is followed by government appointed village sub-chief.

Seventy villagers stated they would report others, if encountered breaking a law, to the persons listed in Table 5. Of the remaining 102 villagers who did not report any of the person in Table 5, 48 said they would either report to the police (20), their fishing captain (11), to the one(s) affected by the rule breaking (9), or confront the person themselves (8). The remaining 54 villagers would not report others breaking the law to any kind of authority. It is important to note that reporting to the police is a daunting task in this rather remote village, so one can assume that only very seriously crime would result in a report. Following this assumption, 74[1] of the interviewed villagers, i.e. 43 %, would not report rule-breaking unless very serious crimes are committed.

Leadership

Identification of key individuals

The identified key individuals are presented in Table 6, in ranked order of centrality. Identified leaders clearly stand out as more centrally positioned compared to the other villagers; a general pattern that reoccurred for all five criteria. For example, the key individuals have direct social ties to 80 (49%) of the other villagers in the combined support and knowledge network. If the reported contacts' ties are also accounted for, key individuals are no more than two relational steps from reaching 132 persons, i.e. 82% of the remaining villagers. Figure 2 shows the combined support and knowledge network among identified key individuals only.

[1] This figure was arrived at by taking the respondents who did not report any specific person (102), subtracting the ones that did report to either the fishing captain (11), the one(s) affected by the rule breaking (9), or the ones that confronted the rule breaker themselves (8).

Table 3 Distribution of strong, self-reported, within-group relations among occupational groups (adopted from Crona and Bodin In press). Size refers to the number of individuals within respective occupation. Rel./Ind. refers to the total number of reported strong relations to individuals irrespective of their occupation, divided by the number of members within the group, and Rel./Ind. in group refers to the number of reported strong within-group relations divided by the number of group members (i.e. bonding ties per group member). Ratio In./Out. (%) refers to the ratio of within-group relations versus all reported relations (i.e. the percentage of bonding ties of that group). Note that the set of villagers presented in this table is limited to those belonging to the listed occupations.

Occupation	Size	Rel./Ind.	Rel./Ind. in group (Bonding ties)	Ratio In./Out. (%) (Bonding/Bridging)
Seine net	16	3,1	2,0	65
Businessman	27	0,7	0,5	71
Farmer	8	0,9	0,3	33
Deep sea	45	3,6	2,7	75
Gill net	10	3,3	1,8	55
Middleman	10	2,0	1,0	50

Table 4 The top five persons cited as alters to whom members of the community would turn for help in solving conflicts. Note that each respondent could cite more than one person.

Person	Number of times cited by villagers
Chairman	143
Sub-chief	85
Deep Sea Fisherman A	17
Former Sub-chief	5
Member of elders' council	5

Table 5 The top five persons cited as alters to whom members of the community would report rule-breaking. Note that each respondent could cite more than one person.

Person	Number of times cited by villagers
Chairman	40
Sub-chief	14
Former Beach Chairman	8
Fisheries officer	6
Deep Sea Fisherman B	4

Table 6 List of identified key individuals and some of their attributes and links to external agencies which they may use for the benefit of other villagers. The last two individuals on the list did not qualify for the top-ten list, as ranked based on centrality criteria, but were included due to their formally appointed positions in the community.

	Leader attributes			**External Contacts**					
				Governmental agencies			**NGOs**	**Finance**	**Market/ Suppliers***
Rank order	**Occupation**	**Age**	**Tribe**	**Fisheries officials**	**Forestry officials**	**Administrative governmental**			
1	Businessman	48	Bajuni		X				
2	Middleman	37	Bajuni	X		X			
3	Retired fisherman	76	Bajuni	X	X	X			X
4	Deep sea fisherman and captain	32	Pemba	X					X
5	Chairman	59	Digo	X	X	X	X		
6	Deep sea fisherman and captain	36	Bondoi	X	X		X		X
7	Deep sea fisherman and middleman	51	Bajuni	X		X		X	X
8	Deep sea fisherman and captain	39	Pemba	X		X			X
9	Deep sea fisherman	40	Pemba						
10	Deep sea fisherman	38	Bajuni						X
>10	Beach chairman and Kigumi fisherman	37	Digo	X	X	X	X		
>10	Subchief	41	Rabai	X	X	X	X		
Sum of contacts:				9 (75%)	6 (50%)	7 (58%)	4 (33%)	1 (8%)	6 (50%)

*Most of the reported contacts with markets/suppliers were related to the provision of different types of fishing related equipment

Key individual characteristics

The ten identified key individuals have similar levels of education, marital status and religion (all are Muslim, as is the absolute majority of all villagers) as the remaining villagers, and most of them have resided in the village for more than 20 years. The only two significant differences between key individuals and other community members are related to tribal membership and occupation (see Table 7A, B). The Bajuni tribe is highly over-represented (50% of the key individuals, but only 12% of the villager population), while the Digo tribe is highly under-represented (10% vs. 49% of the village population). Furthermore, deep sea fishermen are highly over-represented in terms of professions of key individuals compared to other villagers (60% vs. 27%). This could, although only partially, be ascribed to the fact that the network of ecological knowledge exchange was used in identifying key persons, thus non-fishing occupations such as local businessman may have been discriminated. This does not,

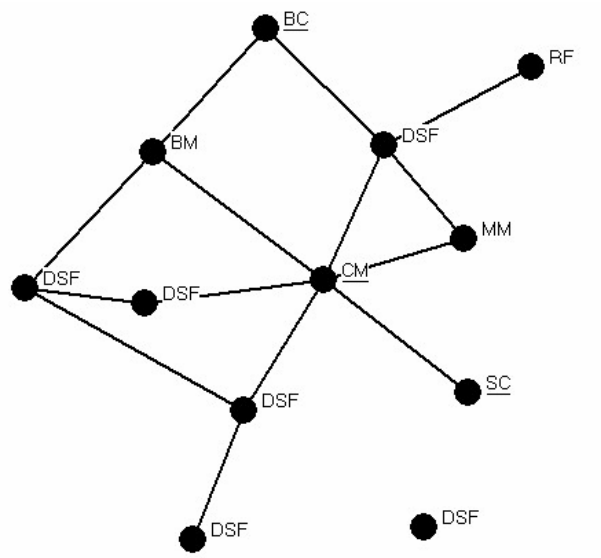

Figure 2. Network of social ties among key individuals. CM=Village chairman, DSF=Deep sea fisherman, MM=Middleman (i.e. fishmonger), BC=Beach chairman, RF=Retired fisherman, BM=Local businessman, SC=Sub-chief. The formally appointed leaders are underlined. Note the central position of the village chairman, as well as the fact that he is the only one connected to the sub-chief. Only one key individual is completely disconnected from the others.

however, explain why there are no other types of fishermen among these individuals. The same skewed representation for tribe and occupation is also seen among the contacts of key individuals, although less pronounced.

In spite of several indicators showing a decline of the fish stocks in the area (McClanahan et al. 1997, Ochiewo 2004), and awareness, on a general level, of this among some fishermen (Crona 2006), only two of the twelve interviewed key individuals recognized that the current situation may jeopardise the continuation of fisheries-based livelihoods. One of the two was not even a fisherman. These two individuals, with a more pessimistic view of the future fisheries, referred to destructive fishing methods and harvesting of under-sized fish as the primary reasons for the current state. Among the ten more optimistic key individuals, two indicated that even though a decline in fish catches seemed apparent new fishing technologies, like better boats and gears, would improve the situation in the future. None of the key individuals had any plans to move away from the village.

Only two were satisfied with the current management of the fisheries. Major complaints were related to the lack of regulation enforcement, but three persons also complained about the ban of seine nets that was recently re-implemented by fishery authorities. These regulations are enforced without the provision of any alternative resources such as loans to fishermen whose fishing gears become illegal or are confiscated.

Ten of the twelve key individuals thought it would be a good idea to designate more responsibility for fishery management to the village, and eight of them would also consider taking a leading part in such management efforts. Only seven could, however, recall any

Table 7 (A) Tribal membership, and (B) Occupations of identified key individuals (Key Ind.) and of the whole population of respondents (Village Pop.).

A			**B**		
Tribe	**Key Ind. (%)**	Village Pop. **(%)**	**Occupation**	**Key Ind. (%)**	Village Pop. **(%)**
Bajuni	50	12	Deep Sea fisherman	60	27
Bondoi	10	<1	Local Businessman	10	16
Digo	10	49	Middleman (fishmonger)	10	5
Pemba	30	26	Chairman	10	<1
			Retired Chairman	10	<1

organizational attempts internally initiated in the village. The two who did not believe in transferring more authority to the village motivated their answers by citing the selfishness of villagers and their inability to report each other.

Almost all key individuals (>90%) agreed on the formal leadership in the village, and they also tended to identify the same set of informal leaders although no single person mentioned all of them. Only one respondent expressed great discontent with current leadership and did not recognize any leaders at all. All key individuals reported the same procedural steps to take in case of fishing-related conflicts and they also identified the same set of trusted persons and authorities as presented in Table 4 and 5.
Three categories of links to external agencies were investigated; links to government agencies, non-governmental organizations (NGOs), and financial institutions and markets (Table 6). Between 50 to 75 % of key individuals reported contacts with government agencies with the highest proportion of links directed at fisheries officials at the local level and fewer to representatives of the forestry department and other administrative bodies (Table 6). Only 33% reported any contact with NGOs and merely one had any contact with a financial institution. While a number of key individuals of the fishing occupation had ties to markets these consisted primarily of contacts for the acquisition of gear, as opposed to contacts for marketing/selling fish. The latter are normally handled by local middlemen (Crona et al. in review).

DISCUSSION

Community social capital

Social capital was assessed from a network perspective as proposed by Borgatti et al. (1998). Average ties per person was 3.7 for the combined social support and knowledge network while 1,3 ties per person if only considering the social support network. This last figure may be compared with outcomes of the 2004 US General Social Survey (GSS) generating an average of approximately two ties per person (SDA Archives, see http://sda.berkeley.edu/archive.htm), and a similar study in urban China (conducted 1993) yielding 3.4 ties per person (Ruan et al. 1997). Despite slight differences in the phrasing of questions, as well as cultural contexts, results are interesting to compare. At first glace our figures indicate lower levels of communication compared to other studies. However, we asked

heads of households to report their ties to others outside their households, while the other studies made no such distinction. For example, approximately 50% of reported ties in an earlier US GSS were to kin (Marsden 1987). Thus, it is fair to assume that a significant number of reported ties in both the US GSS and in China, were also to kin and, if accounted for, the difference between our results and the other studies decreases significantly. The comparison then indicates that average numbers of reported relations in the social support network are within the same order of magnitude for the different cases, although the average number of ties in our study area is likely in the lower range.

Analysis of network components shows only 8% of villagers to be isolates, i.e. not connected to anyone else. The majority of the community belong to a large component seemingly conducive to the formation of social capital according to the line of argument supported by Putnam (2000) and Coleman (1990) where low levels of network fragmentation is argued to enhance social capital by knitting together societies and generating trust. Furthermore, 82% of the villagers (all except the key individuals) are within one or two relational steps from the key individuals, thus indicating that fragmentation is not a major issue for this village.

Bonding social capital describes the links between people with similar objectives while bridging social capital describes the capacity of such groups to communicate with others having different views (Woolcock 2001). The ratio between bonding and bridging ties in the community knowledge network appears fairly balanced with bonding ties accounting for over 50% of reported relations in all but one subgroup yet never more than 75% (Table 3). The bonding/ bridging ratio shows that ties between members of different subgroups, in this case groups based on occupation, provides for communication that spans the whole community, even though most ties exist within subgroups.

The large majority of villagers specifying a contact to ask for help in conflict resolution reported the same set of trusted and/or authorized persons (Table 4). Thus, it seems mechanisms are in place for solving conflicts and that these are recognized by the majority of villagers. It is interesting to note, however, that the local fisheries officer received only 5% of citations even though he is the formal representative of the government in charge of all fisheries-related issues and regulation enforcement.

Looking at social capital from the perspective of attitudes towards sanctioning and self-monitoring, 59% of respondents state no specific person to whom they would report violations of rules or laws, and 43% would not report a violation at all or unless extremely serious and requiring police involvement. It thus appears that, as regards self-monitoring, and subsequently sanctioning, a great part of the community have adopted a rather “laissez-faire” attitude.

Summarizing the situation it appears the level of social capital will depend upon which aspect is in focus. Network measures indicate a potential for relatively high levels of social capital in the village. In addition consensus among respondents exists regarding mechanisms for conflict resolution, yet there is low willingness to report rule breaking. Reluctance to report rule-breaking could actually be reinforced by the coherent social networks spanning almost the entirely village. In fact, many respondents stated they would not report rule-breaking as it

would embarrass the offender and they themselves would risk social rejection. We turn now to an examination of identified key individuals as agents with potential to activate any latent social capital.

Agency and social capital

Krishna (2002) demonstrated that leaders play a crucial role in activating social capital for the benefit of the community by providing villagers with the know-how to manoeuvre bureaucracy to benefit from government programs, and facilitating collective action through coordination and conflict resolution. In addition, from a resource management perspective, leaders can provide links to agencies assisting with information and education (government or NGOs) and be the coordinators of such efforts to maximize the benefit and ensure its implementation. The crucial importance of such boundary-spanning leadership in natural resource management has been identified by several scholars in numerous cases (e.g. Olsson 2003 and Frances Westley, personal communication). Cross-boundary links are assessed here by the ties to external agencies possessed by identified key individuals (Table 6). Results show that they are fairly well connected to external agencies with the exception of financial institutions and markets other than the trade of fishing gear.

Comparing our results with Krishna's (2002) findings, two aspects of social capital and leadership emerge as potentially explaining the observed lack of communal initiatives in regulating the fishery despite declining fish-stocks; low willingness to report rule-breaking and lack, among key individuals, of external contacts related to financial institutions and markets beyond the trade of fishing-gear. Our focus on natural resource management differs from Krishna who looked at community development and it can be argued that the connection between lack of financial links and successful resource management is not intuitively clear. However, lack of financial links arguably limits a leader' ability to support the integration of economic and/or market related components into any initiative relating to common-pool resource management. Such integration may be crucial for the success of these initiatives (cf. Ostrom 1990), e.g. providing investment capital for alternative sources of income and access to new markets. At the same time it must be noted that such links to financial agencies may be held by persons other than the interviewed key individuals.

Some comments on the limitations of using Krishna's (2002) findings to explain lack of common-pool resource regulations in the studied village are in place. First, we studied a small rural, East African village whereas Krishna focused on rural villages in India. Secondly, we used different methods and measurements to assess community social capital, and we also used the data to explain a slightly different outcome variable (natural resource management vs. development). These differences in context and methods obviously reduce the explanatory power of Krishna's theories in our analysis. Although we acknowledge these limitations, we argue that there are still enough similarities to make a comparison meaningful. Rural India and rural East Africa are both developing regions, and despite using different methods to assess social capital we argue that these measures correlate. For example, a high density of social relations is likely to correlate with individuals' degree of participation in village-related activities (measured by Krishna 2002) (cf. Putnam 2000). Similarly, we argue that the

different outcome variables are comparable as development in rural and natural resource dependent villages is closely linked with their collective ability to manage these resources (WRI 2005).

How well do key individuals reflect village heterogeneity?

It is likely that the shortcomings regarding community social capital and agency described above cannot, by themselves, fully explain the lack of resource regulation. Other factors potentially contribute to the current situation. We propose and discuss some of these below.

One factor likely to raise the barrier for initiation of collective action is the lack of problem internalization (c.f. Adams et al. 2003, Haro et al. 2005). Although many villagers are aware of declining fish stocks (Crona 2006), interviews show that the majority of key individuals do not take the intellectual leap and recognize this as a threat for future livelihoods. This gap is likely an effect of their occupational homogeneity. All key individuals who are fishermen or directly involved in fisheries (i.e. all except the chairman, sub-chief and a local businessman) are (or have been) deep sea fishermen. As such they fish mainly outside the reefs, generally use bigger boats moving over larger areas, and can relatively easily relocate fishing efforts to areas further away. Thus, a decline in fish stocks inshore or in the near vicinity of the bay is not perceived as a major problem by them, contrary to fishermen targeting inshore species only (c.f. Agrawal 2002). In addition, the fact that virtually no other type of fishermen is represented in this select group, and that deep sea fishermen (as a group) are centrally positioned in the community network (Crona and Bodin In press), may present a barrier for other fisher groups to initiate collective action. In a broader perspective, homogeneity among key persons is likely to reduce their collective ability to perceive and synthesize new information and knowledge of different kinds (see e.g. Reagans and McEvily 2003, Oh et al. 2004). As such it reduces their ability to adapt to new circumstances (e.g. decline of fish stocks), in fact potentially contributing to lowering the community's adaptive capacity (e.g. Berkes et al. 2003) and ability to respond to change and disturbances.

Coordination versus influence?

Another factor worth consideration in explaining the lack of collective action is the network structure among key individuals. Firstly, it is interesting to note that neither the beach chairman nor the formally appointed village sub-chief qualified for the top-ten list of identified key individuals (through centrality criteria), whereas the village chairman ranked fifth. Thus, the sub-chief, as the only leader in the village formally appointed by government, appears quite loosely attached to informal networks of communication of important matters and/or exchange of information/knowledge about the natural environment. In contrast the elected, but unauthorized as regards official authorities, village chairman is firmly embedded in the village social networks. In terms of information transfer, the chairman thus has a central and powerful position and is the only link to the sub-chief. This is not unusual considering the formal hierarchical structure of government in Kenya, but it creates a situation whereby the chairman obtains a lot of power in the sense that he can 1) decide which issues to bring

forward to the sub-chief (i.e. setting the agenda), and 2) become a block for information flow and agency if he does not perceive the issue at hand as important, or if it conflicts with personal interests.

From a different perspective, possible benefits of the current structure is that initiation and coordination of action can be greatly enhanced because the chairman is firmly embedded and centrally positioned in both the community social networks (Crona and Bodin In press) remaining as well as the network of key individuals. He can thus act on behalf of the villagers, vis-à-vis the sub-chief, by a direct link, i.e. he has the ability to link the whole community to external authorities. However, the chairman may instead be constrained in his capacity to act by these numerous social ties if consensus for course of action is not reached among his reported contacts (c.f. Frank and Yasumoto 1998). For good or bad the community is seemingly highly dependent on the chairman for initiating collective action of any kind. Vulnerability, or reduction of resilience, lies in this dependency and the impact personal characteristics and interests of a single person has on prioritization and decision-making. This is perhaps an inevitable side-effect associated with boundary-spanning leadership, an issue that should be accounted for when arguing for the benefits of such kind of leadership.

CONCLUSION

This study shows that levels of community social capital can differ depending on which aspect is in focus. While social network measures indicate relatively high levels of social capital, reluctance to report rule-breaking was high. This reluctance could actually be reinforced by cohesive social networks and potentially counter-balance the former. The study also identified key individuals and showed them to possess links to a number of external agencies although with a marked shortage of links to financial institutions and markets beyond the trade of fishing-gear. Comparing the results with similar studies (Krishna 2002) shortcomings may help explain the lack of common initiatives in the village to deal with the overexploitation of fisheries. However, if we instead look at the identified strengths, it is interesting to note that relatively high levels of social capital and the existence of various linkages among key individuals to different governmental authorities have not been enough for initiatives regarding resource management to occur.

Other factors likely to influence collective action for resource management were also identified; marked homogeneity of key individuals in terms of occupation and ethnicity, as well as poor problem internalization and recognition of changing ecological conditions within this group; and structural characteristics of the social network among the key individuals revealing one person to occupy a very central position, as well as possessing the only link to the formally appointed sub-chief. It is argued that these factors respectively affect resource management by 1) reducing key individuals' ability to perceive and synthesize new information and knowledge potentially reducing the community's ability to adapt to new circumstances, and 2) by the inherent vulnerability in depending on a single person for connections to formal government officials, as well as the impact personal characteristics and interests of a single person has on prioritization and decision-making. However, it is

recognized that benefits may also be derived from this latter 'bottleneck' by facilitating coordination of collective action initiatives.

Our findings support ideas that efforts directed at enhancing NRM at the community level should pay attention to several aspects of social capital. Furthermore, leadership characteristics, such as links to external agencies; homogeneity and compositions of the most influential individuals; and structural characteristics of the social network among these individuals, may also contribute to a community's potential for management of natural resources. We argue that the methods applied in this study extend the framework developed by Krishna (2002) in a way that enables further investigation of the role of social capital and agency in NRM by local communities. In particular, by using methods based on structural characteristics of the community's social networks, we were able to (1) identify the most influential individuals without having to rely on so-called informed experts, and (2) provide for less context-dependency, thus making is easier to compare different cases worldwide. The latter is crucial in researching (possible) general aspects of social capital, and agency, and their roles in successful community-based natural resource management. By using a structural network approach, it is also easier to communicate finding to a broader audience of researchers who are interested in developing the concept of social capital.

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REFERENCES

Agrawal, A. 2002. Common resources and institutional sustainability. in E. Ostrom, T. Dietz, N. Dolsak, C. Stern, S. Stovich, and E. Weber, editors. *The Drama of the Commons*. National Academy Press, Washington, DC.

Ancona, D. 1990. Outward bound: Strategies for team survival in the organization. *Academy of Management Journal* **33**:334-365.

Berkes, F., C. Folke, and J. Colding, editors. 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge University Press.

Berman, S. 1997. Civil society and the collapse of the Weimar Republic. *World Politics* **49**:401-429.

Bodin, Ö., and J. Norberg. 2005. Information network topologies for enhanced local adaptive management. *Environmental Management* **35**(2):175-193.

Bonacich, P. 1972. Factoring and weighting approaches to status scores and clique identification. *Journal of Mathematical Sociology* **2**(1):113–120.

Borgatti, S. P., and P. C. Foster. 2003. The Network Paradigm in Organizational Research: A Review and Typology. *Journal of Management* **29**(6):991–1013.

Borgatti, S. P., C. Jones, and M. Everett. 1998. Network measures of social capital. *Connections (INSNA)* **21**(2):-36.

Burt, R. S. 2004. Structural Holes and Good Ideas. *American Journal of Sociology* **110**(2):349-399.

Carlsson, L., and F. Berkes. 2005. Co-management: concepts and methodological implications. *Journal of Environmental Management* **75**:65-76.

Coleman, J. S. 1990. *Foundations of Social Theory*. Harvard University Press, Cambridge, MA.

Crona, B. I. 2006. Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. *Ecology and Society* **11**(1):32.

Crona, B. I., and Ö. Bodin. 2006. WHAT you know is WHO you know? Communication patterns among resource users as a prerequisite for co-management. *Ecology and Society (In press)*.

Dale, A., and J. Onyx. 2005. *A dynamic balance: social capital and sustainable community development*, Vancouver, BC, Canada.

Davis, A., and J. R. Wagner. 2003. *Who* knows? On the importance of identifying 'experts' when researching local ecological knowledge. *Human Ecology* **31**(3):463-489.

Degenne, A., and M. Forsé. 1999. *Introducing Social Networks*. Sage Publications, London.

Frank, K. A., and J. Y. Yasumoto. 1998. Linking Action to Social Structure within a System: Social Capital within and between Subgroups. *American Journal of Sociology* **104**(3):642-686.

Freeman, L. 1979. Centrality in social networks. Conceptual clarifications. *Social Networks* **1**:215-239.

Fukuyama, F. 1995. *Trust: The social virtues and the creation of prosperity*. Hamish Hamilton, London.

Gadgil, M., P. R. S. Rao, G. Utkarsh, P. Pramod, and A. Chhatre. 2000. New meanings for old knowledge: The People's Biodiversity Registers program. *Ecological Applications* **10**(5):1307-1317.

Granovetter, M. 1973. The strength of weak ties. *American Journal of Sociology* **76**(6):1360-1380.

King, A. 2000. *Managing without institutions: The role of communication networks in governing resource access and control, Phd Thesis*. PhD. University of Warwick, UK.

Krishna, A. 2002. *Active social capital. Tracing the roots of development and democracy*. Columbia University Press, New York.

Lin, N. 1999. Building a network theory of social captial. *Connections* **22**:28-51.

Marsden, P. V. 1987. Core Discussion Networks of Americans. *American Sociological Review* **52**(1):122-131.

McClanahan, T. R., H. Glaesel, J. Rubens, and R. Kiambo. 1997. The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. *Environmental Conservation* **24**(2):105-120.

McPherson, M., L. Smith-Lovin, and J. M. Cook. 2001. Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology* **27**:415-444.

North, D. C. 1990. *Institutions, Institutional Change and Economic Performance (Political Economy of Institutions and Decision)*. Cambridge University Press.

Ochiewo, J. 2004. Changing fisheries practices and their social implications in south coast Kenya. *Ocean & Coastal Management* **47**:389-408.

Oh, H., M.-H. Chung, and G. Labianca. 2004. Group social capital and group effectiveness: the role of informal socializing ties. *Academy of Management Journal* **47**(6):860–875.

Olsson, P. 2003. *Building capacity for resilience in social-ecological systems (Doctoral thesis)*. University of Stockholm, Stockholm.

Olsson, P., Folke, C. and Berkes, F. 2004. Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management* **34**(1):75-90.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press.

Portes, A. 1998. Social capital: Its origins and applications in modern sociology. *Annual Review of Sociology* **22**(1):1-24.

Pretty, J. 2003. Social capital and the collective management of resources. *Science* **302**:1912-1914.

Pretty, J., and D. Smith. 2004. Social capital in biodiversity conservation and management. *Conservation Biology* **18**(3):631-638.

Putnam, R. D. 1993. *Making democracy work. Civic traditions in modern Italy*. Princeton University Press, Princeton, NJ.

Putnam, R. D. 2000. *Bowling alone: The collapse and revival of American community*. Simon & Schuster, New York.

Reagans, R., and B. McEvily. 2003. Network structure and knowledge transfer: The effects of cohesion and range. *Administrative Science Quarterly* **48**(2):240-267.

Ruan, D., L. C. Freeman, X. Dai, Y. Pan, and W. Zhang. 1997. On the changing structure of social networks in urban China. *Social Networks* **19**(1):75-89.

Schneider, M., P. Teske, M. Marschall, M. Mintrom, and C. Roch. 1997. Institutional arrangements and the creation of social capital: The effects of public school choice. *American Political Science Review* **91**(1):82-93.

Wade, R. 1994. *Village Republics: Economic conditions for collective action in South India*. Institute for Contemporary Studies, San Fransisco.

Wasserman, S., and K. Faust. 1994. *Social Network Analysis - Methods and applications*. Cambride University Press, Cambridge.

Westley, F., and H. Vredenburg. 1997. Interorganizational Collaboration and the Preservation of Global Biodiversity. *Organization Science* **8**(4):381-403.

Volker, B., and H. Flap. 2001. Weak ties as a liability: the case of East Germany. *Rationality and Society* **13**(4):397-428.

Woolcock, M. 2001. The place of social capital in understanding social and economic outcomes. *Canadian Journal of Policy Research* **2**:11-17.

Woolcock, M., and D. Narayan. 2000. Social capital: Implications for development theory, research and policy. *The World Bank Research Observer* **15**(2):225-249.

WRI. 2005. *World Resources 2005: The Wealth of the Poor - Managing Ecosystems to Fight Poverty*. World Resources Institute in collaboration with UNDP, UNEP and World Bank, Washington, DC:WRI.

APPENDIX 1

Interview guideline for leaders identified based on communication network metrics

Section I – Personals

Name:
Age:
Education:
Resident/migrant status:
Occupation:
Income: (self-ranked)
Previous occupation (alliance):
Politically/org active:
Now_____Previously_____

Section II – Leadership

What is a good leader in your opinion?

What does leadership look like in the village? (official leaders, informal leaders, the village council, village committee)

To your knowledge, has there been any form of organized activities (regardless of issues) in the village historically?

If so, can you describe it? (Is it ongoing? If not, why?)

Were you involved and if so how/what role?

Section III – Perception of problems/issues

Do you think people in the village will be able to continue to support themselves through fishing and mangrove harvesting in 10 years time? Explain.

Section IV – Motivation and possibilities for active involvement

Do you see yourself continuing your life in the village in the future? And where do you expect your children to grow up?

Is there anything in the way that natural resources are managed at present in the area that you would like to change? Explain.

Depending on the answer above….
If responsibility for management of natural resources, for example the inshore fishery, would be partly transferred to the community would you like to get involved? If so how?

Would you consider it feasible for you to get involved based on your economic, social, work related etc. situation?

Section V – Krishna's agency variables (modified)

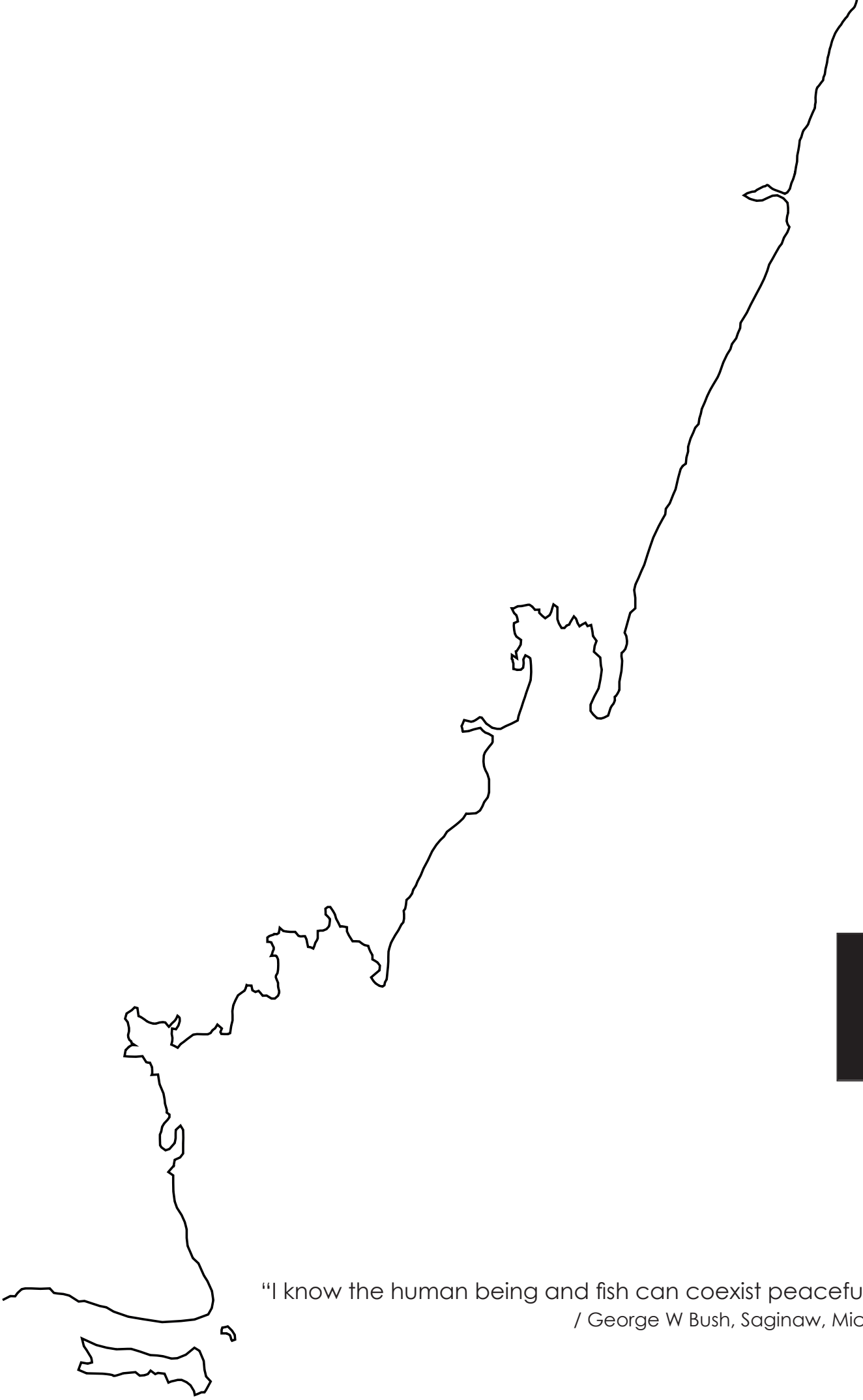
Below follows a list to see which of the following activities the respondent is involved in and to what extent he/she assists other villages in this matter:

• Contact with government departments related to natural resources (indicate which hierarchical level the contact is at)	YES/NO	you/others
▪ Fisheries Department; level	YES/NO	you/others
▪ Forestry Department; level	YES/NO	you/others
• Contact with any other government departments/organizations; level of contact person	YES/NO	you/others
• Contact with any non-government organization; level of contact person	YES/NO	you/others
• Contact with banks and insurance agencies; level of contact person	YES/NO	you/others
• Contact with market/suppliers (Produce markets/hotels/tools/ fishing equipment etc), specify.	YES/NO	you/others
• Providing credit in times of need. How?	YES/NO	you/others
• If someone breaks a law/moral code/norm/social rule what do you think should be done? What do you do?		

Specific questions relevant for certain individuals

• Looking after the affairs of religious buildings, such as the mosque	YES/NO
• Resolving disputes among individual villagers	YES/NO
• Dealing with disputes between husband and wife	YES/NO
• Punishing people who have broken a moral code	YES/NO

After completion of Section V, follow up questions where the respondent has stated that he/she helps others to specify who those others are.



VI

"I know the human being and fish can coexist peacefully."

/ George W Bush, Saginaw, Michigan, 2000

Middlemen as critical links in Social-Ecological Systems: An example from fishing communities in Eastern Africa.

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SUMMARY: To achieve sustainable resource management it is imperative to capture the feedbacks between ecological and social systems. The concept of linked social-ecological systems (SES) represents a departure from conventional management philosophy by treating the two as an integrated system. In this context, we investigate the role of middlemen (fishmongers) in small-scale fisheries in East Africa and their influences on resource exploitation and dynamics. We interviewed fifty fishermen and middlemen from eleven villages on the south coast of Kenya and south west coast of Zanzibar, Tanzania. Results show middlemen as a key link that shape the coastal ecosystem by connecting resource extractors to fish markets and by providing a capital market. Fishermen are tied to middlemen through credit extension resulting in facilitated entrance into the fishing profession, but also restrained livelihood diversity. The function of middlemen as the link between markets and fishermen creates a continuous exploitation pressure on fish stocks and affects resource status and dynamics. We argue that although middlemen have short-term stabilizing effects on the social system by providing financial guarantees during periods of lower catches, they seemingly push the management system in a direction that disconnects extraction pressure from monitoring, responding to and learning about the dynamics of fish populations for sustainable harvests. They also seemingly halt the development of alternative livelihoods, which may cause increased vulnerability in the long-term. These roles of middlemen are seldom accounted for in fisheries governance structures. We outline three future trajectories for small-scale fisheries in the region and discuss the role middlemen may play in shaping these under the influence of external drivers. Because of their significant function in coastal social-ecological systems of East Africa, we propose the development of policies that make use of middlemen for improved governance of fish stocks and coastal ecosystems.

KEY WORDS: *small-scale fishery, middlemen, Social-Ecological Systems, East Africa, resource dynamics, coastal communities*

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INTRODUCTION

Throughout history humans have shaped nature, which in turn has shaped the development of human societies (Redman 1999; Folke in press). The reciprocal influence from resource-use and ecological feedbacks truly depicts the interdependency and interconnectedness between social and ecological systems (Folke in press). From this perspective the two systems can not be treated separately. Subsequently, new analyses are required which focus beyond the purely social or ecological dimensions of

resource and environmental management to interlinked and interdependent systems.

The concept of linked social-ecological systems (SES) has emerged in an effort to make the dynamic interplay between the human and ecological components more explicit, as well as focusing on the feedback mechanisms by which the two are coupled (Berkes & Folke 1998; Folke *et al.* 2005). Identifying such links will enable tracking of the feedbacks between the social and ecological domains, which is essential for efforts aimed at sustainable resource management in complex ecosystems.

Much research effort has focused on how to manage the ecological component while also devising policy instruments to influence resource extractors. While institutions for the management of natural resources are studied extensively, understanding the links between the two for improved ecosystem management and governance is a rapidly developing but largely unexplored area, within the discourse of conservation, natural resource management and linked SES. To date however, links and feedback mechanisms have been addressed from the perspectives of local ecological knowledge among resource users and its effect on resource related institutions and management decisions (Berkes 1999; Olsson & Folke 2001; Aswani 2002); patterns of remittances affecting livelihood diversification and resource exploitation (Adger *et al.* 2002; Curran 2002; Gammage *et al.* 2002; Naylor *et al.* 2002); property rights affecting conservation incentives and resource management (Acheson 1988; Ostrom *et al.* 1999), to name a few.

In this study we investigate another such link in SESs that, to our knowledge, has not previously been examined in this context. This link is represented by middlemen involved in small-scale fisheries. By middlemen we refer to the group of fishmongers that are in direct contact with fishermen at the landing sites, often commissioned as agents for larger collectors (see also Gibbon 1997b). We hypothesize that they may constitute a critical factor of the social system shaping the ecological system in small-scale fisheries in East Africa, and potentially in many other developing regions, as the economic relationship between middlemen and fishers has been described worldwide (Amarasinghe 1989; Merlijn 1989; Meynen 1989). Middlemen directly connect resource extractors to local markets and provide a capital market with effects on exploitation pressure and resource dynamics. Despite such a central role, within coastal SESs they have, as far as we are aware, not been embraced in fisheries governance structures or accounted for in fisheries management and policy to any great extent.

Based on empirical data this paper investigates the nature of middlemen as an informal institution and discusses their potential key role in governing fisheries exploitation by artisanal fishing communities in Southern Kenya and Zanzibar, Tanzania and thereby indirectly shaping ecological dynamics including the capacity of coastal ecosystems to sustain a viable fishery. We argue that middlemen could become valuable actors for information dissemination and implementation of regulatory measures in fisheries management. Based on the proposed function of middlemen in coastal SESs we outline three future trajectories and discuss the role this group may play in shaping these trajectories under the influence of external drivers, as well as the consequences for resource management.

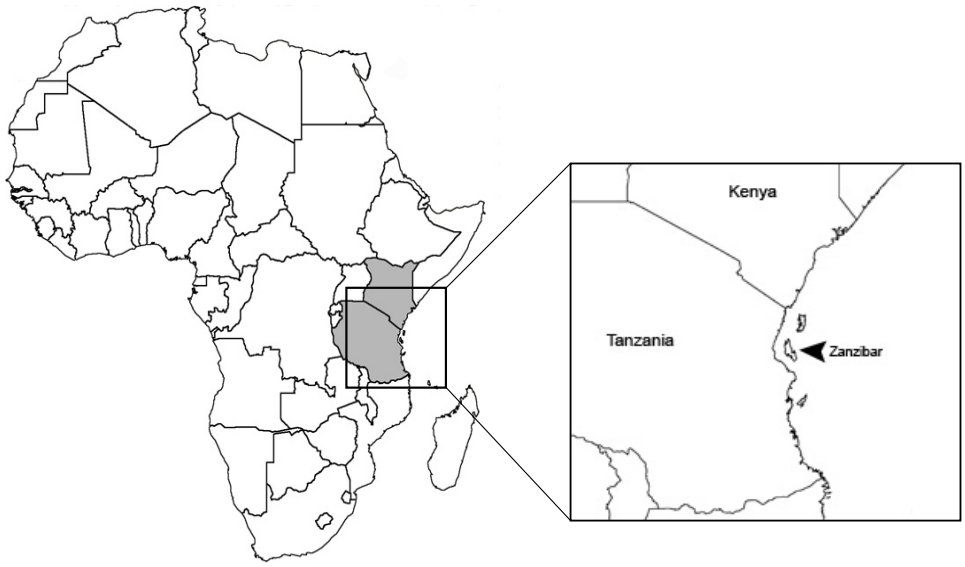


Figure 1. Map showing the two countries in focus in this study. Sampling communities are located along the southern coast of Kenya and along the south and south west coast of Zanzibar.

METHODS

Study areas

Our study includes communities in two areas of Eastern Africa (Figure 1), the southern coast of Kenya, and Zanzibar, Tanzania, both of which are typical of the region in a number of ways. The principal livelihood is centered on small-scale artisanal fisheries and the socio-cultural makeup of the population is similar with predominantly Muslim and Kiswahili speaking, low-income households. In addition, the organization of the local marketing chain for fish and seafood is similar with the existence of middlemen and a dual market consisting of hotels and restaurants catering for a growing tourism industry as well as a market for consumption by local households.

The small-scale artisanal fishery described here is based predominantly on traditional or low-tech gear such as handlines, fish traps, beach seines, and gill nets, while ring nets and spearguns are increasingly being adopted (Crona 2006). Most fishing operations are based on dug-out canoes (*mtumbwi, ngalawa*) or a type of small, traditional sailing vessel (*dhow*). Catches are landed at small landing sites located in or close to local communities typically without any significant infrastructure for fish storage or transportation.

Interview methods

The paper draws on data collected during three separate field trips conducted between March 2004 and October 2005. Interviews were conducted with fifteen middlemen from four different villages on the south coast of Kenya as well as 33 fishermen and 2 middlemen from 7 villages on the south west coast of Zanzibar, Tanzania. In the Kenyan

villages the middlemen interviewed represented between 100 % (one village), to approximately 50 % (two villages) and 25 % (one village) of middlemen operating in each village respectively, calculated based on the number of active middlemen as given by local chairmen, beach chairmen and from previous studies (Crona & Bodin in press). Fishermen interviewed on Zanzibar represented between 5-25 % of the actively fishing community members and were randomly selected based on consent and availability (i.e. presence at the landing site and in the village).

Interviews with both middlemen and fishermen were conducted using a semi-structured interview set-up. Semi-structured in this sense means simply that questions were open-ended so as to give respondents the possibility to freely describe their perceptions and not impose restrictions on the material by the interviewer's preconceived notions. Answers were later coded for analysis. For each respondent data was also collected on the age, number of years in the trade, number of years operating in the area, as well as educational background and prior occupation. In both study areas focus group interviews were conducted with fishermen and middlemen in the initial phase of data collection to identify the issues perceived to be of most importance. These were then followed up by individual interviews.

Interviews with middlemen were designed to elicit information on the following three thematic areas; (i) size of each respondent's operation, market preferences guiding the species composition of sales and purchases, and changes in the fishery over time (catch landings and composition, gear use, number of fishermen and middlemen operating in the area, among others); (ii) the nature of the informal institution (mode of repayment of loans, interests, contracts, generality of arrangements on a wider regional scale as perceived by respondents); (iii) the role and function of the institution (size, frequency and extent of loaning activity and links to dynamics of natural resource extraction). Fishermen interviews focused on fishing operations, markets, and changes in the fishery over time corresponding to theme (i) above, and also included questions on e.g. the nature of credit arrangement, size and frequency of loans and links to dynamics of natural resource extraction thus corresponding to a combination of themes (ii) and (iii).

Interviews lasted 45-75 minutes and were conducted at the respondent's house, at the landing site, or at the house of the village chairman, depending on the preference of the respondent. Respondents were selected as randomly as possible through a process by which the local chairman was approach as a first step to ask for permission to conduct interviews in the area and to explain the nature and purpose of the study. As neither all middlemen nor fishermen were available respondents were selected on the basis of availability and willingness to participate in the study. We thereby acknowledge that pure random sampling was not achieved and that certain knowledgeable individuals may have been excluded. However, as the purpose of the study was to gain a picture of general patterns in the community we judged this approach to be the most scientifically and practically feasible. All interviews were conducted in Kiswahili and simultaneously translated to English using a local interpreter well acquainted with the nature and purpose of the study so as to minimize error due to translation.

RESULTS

Trends in the fishery system

Although catch statistics from the Kenyan coast show big annual fluctuations but no significant declining trends (McClanahan *et al.* 1998) the status of many of the fringing coastal reefs and lagoon habitats in both

Kenya and Tanzania show severe signs of degradation (Obura 2002; Ochiewo 2004). High levels of fishing pressure due to a large influx of people entering the fishing occupation as a result of high unemployment rates and increased use of destructive gears are partly accountable (Crona 2006).

The fishery is characterized by seasonal fluctuations over the year, caused by monsoon winds with calm waters and intense activity during the South East monsoon (SEM) and lower fishing pressure and catches during the North East monsoon (NEM), also documented in other studies (de la Torre-Castro & Rönnbäck 2004). The reason for this lowered activity lies primarily in the nature of the fishing vessels available which cannot withstand rough seas and strong winds. During the SEM the higher catches are largely attributable to the calm weather allowing fishing operations using low-technology gears to access the entire reef area in addition to the lagoon. In some villages catches landed by seasonally present migrant fishing crews (in Kenya) using ringnets and purse seines, and locally referred to as deep sea crews as they target primarily pelagic stocks in the deeper waters off the outer reefs, also add to increased landings during this time. Such migratory fishing operations, locally termed *dago*, exist on Zanzibar as well. In the case of *dago* fishermen gears vary, and the pattern of migration is between the west and the east coast of the island.

Sixty percent of Kenyan and 88% of Tanzanian respondents report a declining trend in catch landings over the last ten years despite the fact that up to 60% of Kenyan respondents in some villages, and a total of 97% of Zanzibar fishermen, claim numbers of fishermen have increased thus indicating declining catch per unit effort (CPU) characteristic of overfished systems. A majority of respondent middlemen (73%) and fishermen (74%) report that the proportion of catch landings consisting of low-value, less marketable fish has increased over the last few years, while the size of fish caught has also declined.

The influence of market demand on species composition and ecosystem dynamics

Interviews with middlemen and fishermen revealed the hotel and tourism industry as a major driver governing the type and amount of fish purchased by middlemen. This market, from now on referred to as the tourism market as it caters to both hotels, restaurants and larger shops, has a big demand for large fish of high quality and commercial value. This type of fish is primarily represented by pelagic and reef associated species like kingfish (Scombridae), red snappers (Lutjanidae), different species of tuna, jacks and trevallies (Carangids) as well sailfish (Istiophoridae), which all in turn are piscivorous thus representing higher trophic levels. Although certain species are preferred by the tourism market the highly dynamic nature of the supply has made size the primary factor determining which market becomes the destination of the fish landed.

Fish purchased for the local market is commonly all the undersized high value fish not marketable for the tourism and restaurant industry as well as all other low and medium value fish of all sizes. This reportedly includes a large amount of undersized fish (sub-adults and juveniles) caught with non-selective gears like beach seines; the proportion of which is reported by respondents in Kenya to have increased dramatically over time. These gears target primarily lagoon dwelling species. Although the local market will absorb virtually all fish landed, favored species include rabbitfish (Siganidae), seagrass dwelling and reef associated parrotfish (Scaridae) as well as emperors (Lethrinidae). Rabbitfish and

parrotfish are predominantly herbivores while most emperors are opportunistic omnivores (Froese & Pauly 2004).

Combining the demand from these two markets exerts a high pressure on both higher and lower trophic levels of the fish community with subsequent influence on ecosystem dynamics (Bellwood *et al.* 2004; Nyström 2006). The tourism market demand fluctuates in accordance with the tourist season coinciding with higher demand during the calmer SE monsoon period. The local market demand, however, is less flexible. This means that during the NE monsoon period when exposed reefs are not accessible the constant demand is satisfied through continuous fishing pressure on lagoonal and inner reefs. The harvests of the small-scale fisheries in both areas studied are thus predominantly consumed at a local scale and not by global markets yet the market created by tourist demand has an underlying global driving force (Berkes *et al.* 2006).

Nature of the informal institution represented by middlemen

The nature of the informal institution represented by middlemen in the fishing communities studied here is best described by looking at the norms and rules that govern the interaction between fishermen and middlemen. These are also summarized in Table 1.

All respondent middlemen report engaging in credit activities, providing loans to fishermen on an as-needed basis, often at irregular and unpredictable times. Sixtytwo percent of fishermen report taking loans from time to time. These loans are issued strongly based on trust. No contracts are written (if not recurring or very large loans) and no interest is charged, in accordance with traditional Islamic conduct. However, loans are used by middlemen to tie fishermen to their operation thus securing income, and loans are seen by many respondent middlemen as a means of business investment. The method of repayment is through fish sales. Fishermen tied to a middleman are bound by strong social norms and a mutual agreement to sell their fish to that specific dealer, and only in cases when the dealer is not available or cannot purchase the entire catch may they sell to other middlemen. Loans are thus paid back gradually through deduction of fish sales at the local landing site.

The size of loans extended differs between respondents. Some middlemen operate on a very small scale with only a few fishermen tied to them. Others are engaged on a much larger scale with as many as 40 fishermen tied to their operations. Consequently the range in size of loans extended varies; from Ksh 100 to 5,000 (USD 1 – 70) and approximately Tsh 1.500 (USD 1) for small-scale middlemen up to Ksh 20,000 (USD 280) or Tsh 200,000 (USD 164) for larger scale operators. Kenyan respondents operating on a larger scale also admit to having two different categories of client fishermen. One category consists of local fishermen to whom loans ranging from Ksh 100 to 1,000 are available while the other is represented by foreign, migrant fishermen with access to loans ranging from Ksh 3000 to 20,000 (USD 42-280). Much of this money is used for travel arrangements, permits, and cost for food and housing during their stay. The size of loans available will also depend on the type of species targeted by fishermen such that those targeting high value species like e.g. lobsters, tuna and kingfish will be granted access to larger loans. This is a direct consequence of the profit maximizing incentives by dealers and their professed attitudes towards credit activities as business investment. When asked about the history of the middleman profession and the associated credit activity, all middlemen stated that the ability to provide credit for fishermen is an essential part of the 'job description' and to their knowledge had been so for as

Table 1. The nature of the institution represented by middlemen described by a number of rules and norms defining the credit exchange relationship between middlemen and credit-seeking fishermen.

The nature of the institution represented by middlemen
Loans are based on trust. Most often no contracts are written (only for very large or recurring loans that have not yet been paid back).
Sometimes middlemen act as a bank for migrant fishermen, accumulating fishermen's profit from fish sales and paying a lump sum at the end of a given period of time. This pattern is practiced for migrant fishermen only.
No interest is charged on loans but loans are used by middlemen to secure income by tieing fishermen to their business.
The credit activity reportedly has existed for as long as middlemen have been a part of the fish marketing chain.

long as the trade in fish has existed.

Current role of middlemen in coastal social-ecological systems

The current role and function of middlemen in coastal, and primarily rural, SESs in East Africa is outlined in Table 2. Two main factors define this role and the effect on social and ecosystem dynamics; the provision of credit and the creation of a direct link to outside markets. By providing credit to local fishermen on an as-needed basis, at irregular and unpredictable times, middlemen buffer income variations of fishermen due to seasonal fluctuations in fish catches. All middlemen interviewed report an increased frequency of extended loans during the North East monsoon while 75% also testify to trends of increasing demand for loans during this period, over time, as a result of increasing numbers of fishermen but also lower catches. The obvious effect of credit availability is a direct economic benefit to the fishermen obtaining loans, at least in the short term, and it can be used to invest in maintenance or purchase of gear or simply to buffer periods of low income from fishing. However, this buffering capacity may have secondary effects on social dynamics and attitudes as well as their consequent effect on resource use as will be discussed in detail below.

As described above, and in addition to providing credit, middlemen also effectively channel the different market demands such that the tourism market becomes available to the average small-scale artisanal fisherman. This, naturally, is beneficial from the perspective of the individual gaining market access and income. It also has a direct effect on the level of fishing and the distribution of this exerted pressure over the seasons as well as influencing which species are primarily targeted, with effects on functional groups and ecological processes governed by those functions.

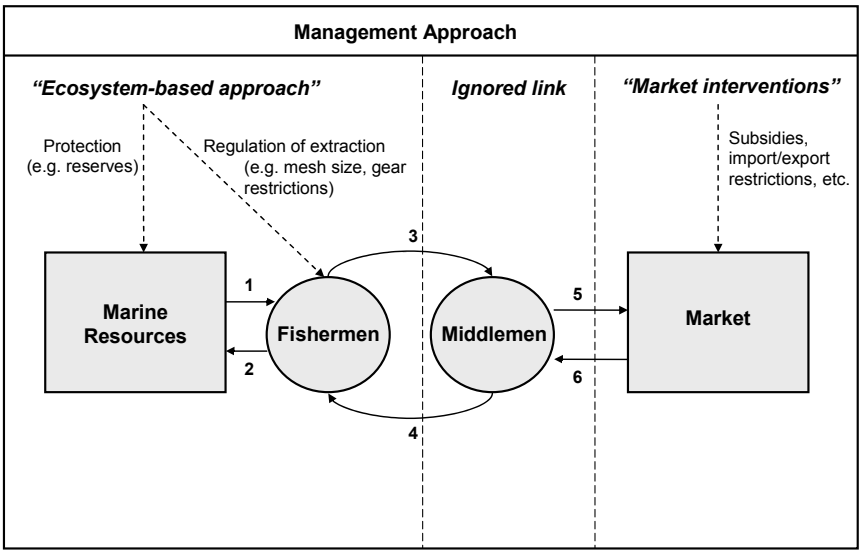
Table 2. The current role and function of middlemen in social-ecological dynamics as defined by the effects of feedback mechanisms channeled through middlemen.

Current role and function of middlemen	
Middlemen buy fish from fishermen and sell to a 3rd party (hotels, shops, other suppliers, local market).	- Represents a direct link between the market and the resource extractors.
Prioritization of certain species. Middlemen select fish firstly for the hotel/tourist industry and secondly for the local market.	- Effects on which stocks are targeted with potential consequences for diversity of, and within, functional groups of fish, and through this ecosystem dynamics and potential regime shifts of tropical coastal ecosystems.
Provision of credit (money and gear) to fishermen at irregular and unpredictable times.	- Buffers income variations due to seasonal fluctuations in fish catches - Effects on which stocks are targeted and when through (i) travel loans to migrant fishermen and (ii) through provision of loans buffering low income and affecting incentives for livelihood diversification. - Effects on the social dynamics of the fishing community by facilitating the entrance of migrant fishermen into the system with indirect effects on resource extraction patterns by local fishermen.

DISCUSSION

The framework of linked social-ecological systems (SES) emerged in an effort to make the interplay between the human and ecological components more explicit as well as focusing on the feedback mechanisms by which the two are coupled (Berkes & Folke 1998; Folke *et al.* 2005). Implementing this framework in policy requires ability to identify critical links that couple the social and ecological components. This empirical study adds to the literature on such links by investigating middlemen involved in the small-scale artisanal fishery in East Africa. The process of tieing fishermen to middlemen operations has been described in other parts of the world (see e.g. Amarasinghe 1989; Merlijn 1989; Gibbon 1997b), but the relation and effects on resource and ecosystem dynamics have not previously been addressed. Disregarding such links leads to incomplete conclusions and recommendations for environmental management and policy (Huitric 2005). Such social mechanisms, like the role of middlemen, affecting ecosystem dynamics and feeding back into livelihood options and capacity for sustainable resource use, are likely to also exist in regions outside Eastern Africa.

Middlemen as a professional group have the characteristics of an informal institution, vis-à-vis the fishermen, in the sense that they define and limit the set of choices available



1. Extraction of fish
2. Prioritization of certain species based on market preferences channeled through middlemen
3. Fishermen generate income for middlemen and are tied to them through loans
4. Middlemen provide credit for capital investment and during times of low catch, which feeds back to the resource base in the form of increased/more efficient extraction mechanisms
5. Middlemen respond to the market demands and provide artisanal fishermen access to otherwise inaccessible markets Results in species preferences also reflected in the direct resource extraction (see 2.)
6. Preferences of different markets (local, regional and global) drive prioritization of species demanded/favored by middlemen

Figure 2. Conceptual model of the links and feedback loops in a simplified coastal SES. Examples of different management approaches are depicted in relation to the component/actor group they are designed to target and the process(es) by which regulation is conventionally achieved. These different approaches are not mutually exclusive but are rarely adopted in tandem. The 'ignored link' in focus in this paper is represented by middlemen (fishmongers) and presents an often overlooked component in fisheries management.

to this group of resource users (North 1990). The feedback mechanisms between the social and ecological system operating through them makes the link strong and persistent. Looking at the nature of the institution this becomes obvious. In the rural East African setting middlemen are most often the only source of available credit for artisanal fishermen. Strong social ties generating trust and reciprocity, often termed social capital (Woolcock & Narayan 2000), is a common feature of many small, tight-knit communities (Narayan & Pritchett 1999; Krishna 2002) and provides the setting in which a credit system based on these features, rather than formal contracts and interest payments, can operate. This arrangement allows for the tieing of fishermen by middlemen in order to secure income and generate business, which creates a strong two-way dependency. Middlemen are a comparatively small group of agents in the small-scale fisheries sector compared with the number of fishermen. This bottleneck, through which the majority of fish trading has to proceed, further strengthens the linking feature of middlemen as a professional group.

Middlemen – buffers or barriers? Effects on social and ecological dynamics

The role of middlemen in creating access to new markets has been addressed in the literature, along with increasing fishing pressure and changing fishing behavior, such as extending traditional fishing seasons and

targeting species demanded by the market (Gibbon 1997b; Andersson & Ngazi 1998). By channeling demands for certain high-value species, higher level trophic groups are targeted signaling the risk for fishing-down-the food-web if left unregulated (Jackson *et al.* 2001; Pauly *et al.* 2005). Discrepancies in credit availability to fishermen depending on the scale of fishing operations may also create negative feedbacks re-enforcing a state where continued use of non-selective gears causes decline in stocks of lower trophic groups. Such organism groups may be essential in maintaining ecologically important functions (e.g. Bellwood *et al.* 2004).

The credit provision may have both positive and negative impacts on the social and ecological dynamics of the coupled system. On the one hand loans have the potential to mitigate destructive fishing when fish-stocks are low or contrarily, disconnect the harvesting pressure from dynamics in natural fish populations and climatic cycles, thereby promoting constant unsustainable harvest levels throughout the year.

Buffering periods of low income is beneficial to the individual and has a stabilizing effect on the social system at the village level in the short term. However it also affects individuals' attitudes toward the need for diversification of livelihoods over time. Data collected during separate but parallel studies in south Kenya show a majority of fishermen to report no alternative livelihood or long-term sustainable secondary income source (Crona unpublished data 2005). Availability of credit during low fish harvest periods arguably undermines the perceived need to diversify income sources. This is likely to gradually undermine the resilience of the integrated SES as livelihood diversity is put forth as essential in alleviating poverty and promoting sustainable development in rural communities by spreading the dependence of households over several resources thus reducing vulnerability (WRI 2005). Gradual decoupling between resource users and natural fluctuations in the resource base is a common phenomenon in industrialized societies where such dynamics are largely masked and continuous production of ecological goods and services achieved through technological enhancement (Ludwig *et al.* 1993; Pauly *et al.* 2002; Huitric 2005). The buffering capacity of credit availability may have a similar effect in this region. Barnes (1976) describes 'peasant fishermen' in Tanzania combining farming and fishing according to season. The current situation indicates a shift away from this dual livelihood strategy in the Kenyan communities studied, where the fishing occupation has taken prevalence and where personal and occupational identity is strongly related to the fishing profession (Glaesel 2000; Crona 2006). On Zanzibar, however, fishermen report between 28-37% of their income as coming from alternative sources, such as farming and carpentry, etc., suggesting the adaptive capacity of the community through alternative income sources may be higher in this area.

Another effect of credit availability is the potential opening of the SES to exploitation by foreign fishing operations and the consequences of this on local development; a scenario well illustrated by a Kenyan example. In one Kenyan community studied, characterized by increasing fishing pressure and a seasonally large influx of migrant fishermen from neighboring Tanzania, over 85% of all middlemen actively seek to recruit these migrant fishermen by extending credit for travel, permits and living expenses. The reason given for this behavior, by respondents, is that foreigners are considered more skilled, have larger vessels and crews and are able to target pelagic stock often not accessible to local fishermen due to a lack of gear. In line with the ideas of profit maximizing and high return on investment expressed by middlemen, extending credit

for such operations is a sound business investment as the foreign crews are unofficially bound by social norms to sell their catch through their agent/middleman. Local fishermen are viewed as a larger risk because they have simpler gear, catch less fish and are thought to have a lower ability to pay back big loans. Consequently only small capital is extended to them. This has developed into a vicious circle sending the system off on a potentially destructive trajectory as local fishers have difficulty accessing substantial capital for investment in gears that would allow deeper water operations and have resorted to destructive fishing gears despite being aware of the dire consequences. This is supported by reports of illegal gears like beach seines and spearguns to have increased substantially in the area over time. Thus, foreign fishermen proceed to fish substantial quantities of fish in Kenyan coastal waters generating income for their own operations as well as their agent middlemen, and, through trickle-down effects, for some local shops, eateries and landlords. This does not, however, benefit the majority of local fishermen, representing the lion part of the population. Similar scenarios are described from other parts of the region (Gibbon 1997b), essentially locking local fishers in a poverty trap.

Implications for management

The informal institution represented by middlemen becomes interesting in the context of natural resource management due to its linking function described above and the potential to enhance current management strategies by making use of it to better communicate management objectives to local users and to implement regulations. The linking function could also be exploited by external actors resulting in less desirable outcomes from a sustainable management perspective. Below we outline three different trajectories for the development of small-scale coastal fisheries based on above

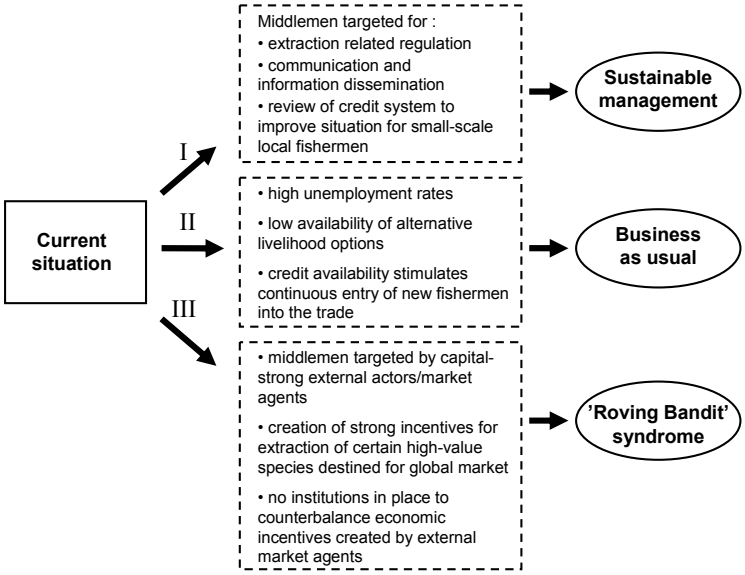


Figure 3. A description of the role played by middlemen in three possible trajectories for future development of small-scale coastal fisheries in Eastern Africa. Dashed boxes describe the role of middlemen in combination with other factors identified as important for defining the trajectory.

presented assumptions about the role of middlemen; I) Sustainable management, II) Business as usual, and III) the 'Roving Bandit' Syndrome (as described by Berkes *et al.* 2006) (Figure 3).

To promote the Sustainable management trajectory we propose three ways in which this institution could be targeted with the aim of producing benefits from both a social and ecological perspective. Firstly, the bottleneck occupied by local middlemen in the marketing chain (Figure 2) offers a more feasible target for regulatory measures than fishermen. Government controlled monitoring and enforcement of fishing regulations in small-scale fisheries, where fishing is done at all hours of the day and operations are many and dispersed, becomes an often prohibitively expensive and difficult task without neither formalized structures for reporting catch landings nor sufficient resources. In addition, in cases where tieing of fishermen through credit shows tendencies of turning into wage-labor contracts (Gibbon 1997a), fishermen are merely working for an agent controlling operations. Imparting restrictions on contracted laborers is arguably less efficient, if even productive, than targeting the whole operation represented by the contractor (middleman).

A second approach is to target middlemen for communication of current management strategies using this group as a valuable tool in disseminating information to fishermen. Again, this group constitutes a bottleneck to which the majority of fishermen are tied in some way but middlemen as an occupational group have also explicitly been shown to occupy a relatively central position in the communication network for transmission of knowledge and information about resource extraction, at least in Kenya (Crona & Bodin 2006).

Finally, as seen above, provision of credit can have both positive and negative influences on SES dynamics. The hampered development potential and essential catch-twenty two for locals, characterized by influx of migrant fishermen and related loan schemes is one example. Not only does this situation undermine local development potential by channeling realized capital from fishing out of the country, with only minor trickle down effects, but it also affects the incentive structures for conservation and sustainable management. When local and national conservation issues are raised the stakeholders most often proposed to have the highest stake in sound management, and therefore suggested to carry the brunt of the cost, are the local fishermen. These fishermen are the poorest and have the least buffer through alternative income and capital. They are not favored even by local lenders and do not even fish a large part of the total fish landed yet they are called upon to conserve the resource by reducing fishing efforts.

The second trajectory, Business as usual, assumes that the role of middlemen, as described here, remains unchanged. High levels of unemployment have been seen to cause increased influx of new fishermen into the trade (Glaesel 2000; Crona 2006), increasing the pressure on resources and straining existing local institutions for managing the common fishery (Glaesel 2000). As these factors coincide with relatively easy access to credit for gear investment through association with middlemen, a trajectory where coastal fish resources are increasingly more overexploited and resilience of the linked SES gradually undermined is foreseen (Figure 3).

The third and final trajectory is based on a situation described by Berkes et al. (2006) as the 'Roving Bandits' Syndrome. This syndrome can essentially be explained as a sequential exploitation of local and regional marine stocks, driven by the demands of a

globalized export market and facilitated by highly mobile market agents and exploiters. Given the linking function of middlemen described here, and the effect of feedbacks between the market and resource base channeled through this group (Figure 2), they have the potential for playing a key role in facilitating and accelerating exploitation by 'Roving Bandits'. Their linking position makes them a likely target for external agents looking to gain access to local stocks for exploitation. Through their tight links to local resource extractors and their power to channel market preferences to fishermen for exploitation of specific target species, they have a great potential to accelerate local resource depletion. In the absence of strong local institutions to counterbalance the short-term, but nonetheless strong, economic incentives offered by temporary access to a global market, there is little hope for the slow-responding, bureaucratic structures often associated with common property resource management (Cordell & McKean 1992; Ascher 2001; Alidina 2005) to identify and halt the phenomenon before the depletion of local stocks has occurred, and the 'Roving Bandits' have moved on.

The three scenarios outlined above are based on our analysis of the current role of middlemen in small-scale fisheries in East Africa. Keeping in mind the role and effect of middlemen on the integrated social-ecological dynamics described here, we hope to have shed some new light on the current situation. The phenomenon of middlemen as an important component in small-scale fisheries exists in developing countries in many parts of the world (Amarasinghe 1989; Merlijn 1989; Meynen 1989). Understanding such critical social mechanisms and their role in social-ecological systems dynamics is essential for sustainable management of resources and ecosystem services (Folke *et al.* 2005). Since social mechanisms like the role of middlemen in small-scale fisheries, is critical they should be identified and embraced into fisheries management and policy.

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REFERENCES

Acheson, J. (1988) *The Lobster Gangs of Maine*. Hanover: University Press of New England.

Adger, N., Kelly, M., Winkels, A., Quang Huy, L. & Locke, C. (2002) Migration, remittances, livelihood trajectories, and social resilience. *Ambio* **31**: 358-365.

Alidina, H. (2005) Local level fisheries management in Diani-Chale, Kenya: Current status and future directions. *Coastal Management* **33**: 459-470.

Amarasinghe, O. (1989) Technical change, transformation of risks and patronage relations in a fishing community of South Sri Lanka. *Development and Change* **20**: 701-733.

Andersson, J. & Ngazi, Z. (1998) Coastal communities' production choices, risk diversification, and subsistence behavior: Responses in periods of transition. *Ambio* **27**: 686-693.

Ascher, W. (2001) Coping with complexity and organizational intersets in natural resource management. *Ecosystems* **4**: 742-757.

Aswani, S. (2002) Assessing the effects of changing demographic and consumption patterns on sea tenure regimes in the Roviana Lagoon, Salomon Islands. *Ambio* **31**: 272-284.

Barnes, C. (1976). A study of the peasant fishing economy in Tanzania - a case study of coastal fishing villages in Dar es Salaam and Coast Regions. University of Dar es Salaam.

Bellwood, D.R., Hughes, T.P., Folke, C. & Nystrom, M. (2004) Confronting the coral reef crisis. *Nature* **429**: 827-833.

Berkes, F. (1999) *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*. Philadelphia: Taylor & Francis.

Berkes, F. & Folke, C. (1998) *Linking Social and Ecological Systems*. Cambridge: Cambridge University Press.

Berkes, F., Hughes, T.P., Steneck, R.S., Wilson, J.A., Bellwood, D.R., Crona, B., Folke, C., Gunderson, L.H., Leslie, H.M., Norberg, J., Nystrom, M., Olsson, P., Osterblom, H., Scheffer, M. & Worm, B. (2006) Ecology - Globalization, roving bandits, and marine resources. *Science* **311**: 1557-1558.

Cordell, J.C. & McKean, M. (1992) Sea tenure in Bahia, Brazil. In: *Making the Commons Work: Theory, Practice and Policy,* ed. al, B. D. W. e. Oakland, CA: ICS Press.

Crona, B.I. (2006) Supporting and enhancing development of heterogeneous ecological knowledge among resource users in a Kenyan seascape. *Ecology and Society* **11**: art 32, http://www.ecologyandsociety.org/vol11/iss1/art32/

Crona, B.I. & Bodin, Ö. (2006) What you know is who you know? Patterns of communication as prerequisites for co-management. *Ecology and Society (In press)*.

Curran, S.R. (2002) Migration, social capital and the environment: considering migrant selectivity and networks in relation to coastal ecosystems. *Population and Development Review* **28**: 89-125.

de la Torre-Castro, M. & Rönnbäck, P. (2004) Links between humans and seagrasses- an example from tropical East Africa. *Ocean & Coastal Management* **47**: 361-387.

Folke, C. (2006) Resilience: the emergence of a perspective for social-ecological systems analyses. *Global Environmental Change (In press)*

Folke, C., Hahn, T., Olsson, P. & Norberg, J. (2005) Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources* **30**: 441-473.

Froese, R. & Pauly, D.E. (2004) Fishbase. World Wide Web electronic publication. In: *version (06/2004)*. http://www.fishbase.org

Gammage, S., Benítez, M. & Machado, M. (2002) Property rights, multiple stakeholders and competing demands: the challenges of mangrove management in El Salvador. *Ambio* **31**: 285-294.

Gibbon, P. (1997a). Of saviours and punks: The political economy of the Nile perch marketing chain in Tanzania. Center for Development Studies Working Paper, Copenhagen.

Gibbon, P. (1997b) Prawns and piranhas: the political economy of a Tanzanian private sector marketing chain. *Journal of Peasant Studies* **25**: 1-86.

Glaesel, H. (2000) State and local resistance to the exapnsion of two environmentally harmful marine fishing techniques in Kenya. *Society and Natural Resources* **13**: 321-338.

Huitric, M. (2005) Lobster and conch fisheries of Belize: a history of sequential exploitation. *Ecology and Society* **10**: art21, http://www.ecologyandsociety.org/vol10/iss1/art21/

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. & Warner, R.R. (2001) Historical overfishing and recent collapse of coastal ecosystems. *Science* **293**: 629-638.

Krishna, A. (2002) *Active social capital. Tracing the roots of development and democracy*. New York: Columbia University Press.

Ludwig, D., Hillborn, R. & Walters, C. (1993) Uncertainty, resource exploitation, and conservation: Lessons from history. *Science* **260**: 17-36.

McClanahan, T., Maina, J. & Pet-Soede, L. (1998) Effects of the 1998 Coral Morality Event on Kenyan Coral Reefs and Fisheries. *Ambio* **31**: 543-550.

Merlijn, A.G. (1989) The role of middlemen in small-scale fisheries: A case study of Sarawak, Malaysia. *Development and Change* **20**: 683-700.

Meynen, W. (1989) Fisheries development, resources depletion and political mobilization in Kerala: The problem of alternatives. *Development and Change* **20**: 735-770.

Narayan, D. & Pritchett, L. (1999) Cents and sociability: Household Income and social capital in rural Tanzania. *Economic Development and Cultural Change* **47**: 871-897.

Naylor, R.L., Bonine, K.M., Ewel, K.C. & Waguk, E. (2002) Migration, markets, and mangrove resource use on Kosrae, Federated States of Micronesia. *Ambio* **31**: 340-350.

North, D.C. (1990) *Institutions, Institutional Change and Economic Performance (Political Economy of Institutions and Decision)*: Cambridge University Press.

Nyström, M. (2006) Redundancy and response diversity of functional groups: implications for resilience of coral reefs. *Ambio* **35**: 30-35.

Obura, D. (2002) Status of coral reefs in East Africa. In: *Coral Reef Degradation in the Indian Ocean, Status Report 2002,* eds. Lindén, O., Souter, D., Wilhelmsson, D. & Obura, D., pp. 15-20. Sweden: Cordio, University of Kalmar.

Ochiewo, J. (2004) Changing fisheries practices and their social implications in south coast Kenya. *Ocean & Coastal Management* **47**: 389-408.

Olsson, P. & Folke, C. (2001) Local ecological knowledge and institutional dynamics for

ecosystem management: A study of Lake Racken Watershed, Sweden. *Ecosystems* **4**: 85-104.

Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B. & Policansky, D. (1999) Revisiting the commons: Local lessons, global challenges. *Science* **284**: 278-282.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. & Zeller, D. (2002) Towards sustainability in world fisheries. *Nature* **418**: 689 - 695.

Pauly, D., Watson, R. & Alder, J. (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B-Biological Sciences* **360**: 5-12.

Redman, C.L. (1999) *Human Impact on Ancient Environments*. Tucson: University of Arizona Press.

Woolcock, M. & Narayan, D. (2000) Social capital: Implications for development theory, research and policy. *The World Bank Research Observer* **15**: 225-249.

WRI (2005). World Resources 2005: The Wealth of the Poor - Managing Ecosystems to Fight Poverty. World Resources Institute in collaboration with UNDP, UNEP and World Bank, Washington, DC:WRI.