Thesis for the Degree of Master of Fisheries Science

Ecosystem-based Fisheries Assessment and Management in the Kenyan Coral Reef Ecosystem

by

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캐냐 산호초 생태계에서의 생태계 기반 어업 평가와 관리

Advisor: Prof. Chang Ik Zhang

by

Isaac Wafula Barasa

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Acronyms

CPUE……Catch per unit effort

EBFA……Ecosystem-based fisheries assessment

F……Fishing mortality rate

KWS……...Kenya Wildlife Service

$\bar{L}$ ……..……...L – bar

Limit RP……Limit reference point

Madema……Traditional fishing gear made of palm leaves

MNP……...Marine national park

MNaR……Marine national reserve

MSY……...Maximum sustainable yield

MEY……...Maximum economic yield

Target RP……..Target reference point

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Abstract

This thesis describes the types of coral reefs and coral reefs distribution in Kenya. It highlights the reefs productivity, functions, describes the Coral reefs fishery, management tools, available catch data and social economics of coastal fishing communities of Kenya.

In this study twelve indicators for sustainability, seven indicators for biodiversity, ten indicators for habitat quality and fifteen indicators for socio-economy management objectives were developed. Each of the indicators was assigned level of magnitude that it affects the coral reef ecosystem. Target and limit reference points for each of the indicators were developed also. The target reference point in this application corresponds to a state of each indicator that is considered desirable, while the limit reference point is defined as the limit beyond which the state of each indicator is not considered desirable. Species were assigned a status for each indicator to denote risk. The risk indices for each indicator were calculated. The Kenyan coral reef ecosystem was assessed by the Tier 2 approach based on the quality of data available. From the assessment of twelve fish species risk indices by the

Tier 2 approach, the Kenyan coral reef ecosystem had 39.6 % of the indicators in the desirable green zone, 55.3 % in the yellow zone and 5.1 % in the red zone.

Three fisheries namely; the gillnet fishery, hook and line fishery and traditional trap fishery had risk indices in the yellow zone. Purse seine fishery had risk index in the desirable green zone. This fishery has a draft management plan that guides its fishing operations at the moment. The three other fisheries do not have fisheries management plans. This explains why they have high risk indices. Ecosystem risk index of the Kenyan coral reef ecosystem was assessed based on the fishery risk indices. The Kenyan coral reef ecosystem has risk index '1.10'. This risk index falls in the yellow zone.

In conclusion a better system of data collection for this coral reef ecosystem is required to enable assessment of risk indices by the Tier 1 approach. The results can then be compared with results from the Tier 2 approach. The Kenyan coral reef fisheries management system needs to be organized into four management objectives suggested in this study. Ecosystem approach to fisheries management is currently the core reference point for all fisheries management strategies. Fisheries management plans in line with ecosystem approach to fisheries management are suggested to reduce high risk indices. However climate change is expected to influence species diversity, movement, recruitment etc in many ecosystems of the World. Therefore the Integrated Fisheries Risk Analysis Method for Ecosystems (IFRAME) approach that tracks climate change impacts is suggested for the Kenyan coral reef ecosystem for future study, since the IFRAME framework is made up of three components: assessment, forecast, and management.

Chapter 1. Introduction.

1.1. Background of the research

There has been emerging factors in fisheries management which include; 1. Increasing awareness of the importance of the interactions among fishery resources and between fishery resources and the ecosystem. 2. Environmental effects on fishery resources and effects of fishing on non-target species and habitats, food-chain effects and biodiversity. 3. Recognition of a wide range of societal interests in marine ecosystems. 4. The compelling need to expand fisheries management objectives to include ecosystem considerations (Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem, Oct 2001).

1.2. History of research

Based on the factors mentioned above compounded with the many problems experienced in the management of fisheries activities in the Kenyan coral reef ecosystem. I proposed to carry out this research to solve these emerging factors. Fisheries department in Kenya collets fish landings data that lacks scientific backgrounds required for comprehensive assessment. Two options

for this research were available. These were the Tier 1 approach that requires comprehensive and qualitative data and the Tier 2 approach that requires quantitative data. Based on the quality of data that was available, the Tier 2 approach was the best option for the ecosystem-based assessment and management in the Kenyan coral reef ecosystem.

1.3. Purpose of the study

The purpose of ecosystem-based fisheries management is to plan, develop and manage fisheries in a manner that address the multiplicity of societal needs. This study was therefore undertaken to address the declining trend of coral reef fisheries, lost biodiversity, habitat degradation and solve socio-economic considerations for the Kenyan coral reef ecosystem.

The objectives of this study therefore are; Ecosystem-based assessment and management of the Kenyan coral reef ecosystem with specific objectives as; 1. Describe coral reefs distributions along the Kenyan coastline. 2. Suggest management objectives and associated attributes. 3. Development of indicators, targets and limit reference points. 4. Assessment of risk scores for indicators, objectives, species, fisheries and ecosystem (Tier 2 approach).

5. Suggestions for proper management strategies to reduce high risk indices in line with ecosystem approach to fisheries management.

1.4. Organization of the study

This study is organized into eight chapters as follows; Chapter one deals with the introduction and highlights why this study was undertaken. Chapter two deals with characteristics of coral reefs. Identification of management objectives, fishery management tools and suggested management objectives are discussed in chapter three.

Development of indicators for the Tier 1 and Tier 2 approaches for the assessment of coral reef ecosystems for the four objectives is discussed in chapter four. Development of target and limit reference points, assessment of risks using reference points for the coral reef ecosystems is discussed in chapter five. Chapter six of this study deals with the identification of major fisheries and fish species by fishing gears and assessment of risk indices to each indicator for the twelve species of the Kenyan coral reef ecosystem. Species risk indices, fishery risk indices and ecosystem risk index are evaluated in chapter seven. Suggestions for proper management measures

based on the evaluated risk indices and conclusions are discussed in chapter eight.

1.5. Description of coral reefs

Coral reefs are colonies of tiny animals found in marine waters that contain few nutrients. Most coral reefs are built from stony corals, which in turn consists of polyps that cluster in groups. Coral reefs occupy less than 0.1% of the World's Oceans surface, but provide home for 25% of all marine species including; Fish, Mollusks, Worms, etc. Annual global economic value of coral reefs is estimated at USD 375 Billion. Coral reefs are fragile ecosystems under threat from climate change, ocean acidification, destructive fishing activities, overuse of reef resources and pollution. (Muthiga et al. 2008)

Without coral reefs protecting the shoreline from currents, waves, and storms there will be loss of land due to erosion (Lundberg and Moberg, 2003). The capacity of coral reefs to dissipate wave energy creates lagoons and sedimentary environments (Figure 1.1).

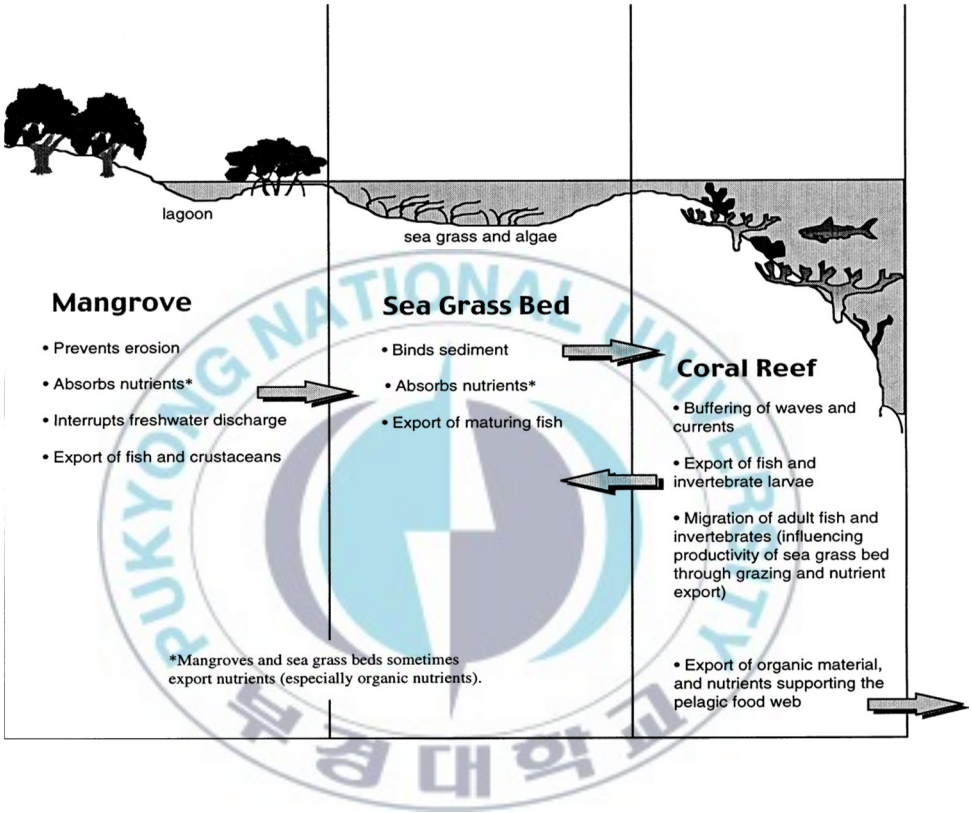

Fig. 1.1. Interactions in the tropical seascape, showing the connections between mangroves, sea-grass beds and coral reefs (Adopted from White (1986) and Ogden (1988)).

The Kenyan coral reef represents fringing reefs that closely follow shorelines and narrow shallow lagoons (Figure 1.2). Kenya coral reef is ranked number 54 in the world in terms of area, i.e. 630km^2 approximately 0.22% of the world's total coral reef area. The coral reefs existing along most of the Kenya coast occur as coral flats, lagoons, reef platforms, and fringing reefs with most native fish species and 183 species of stony corals belonging to 59 genera identified on these reefs.

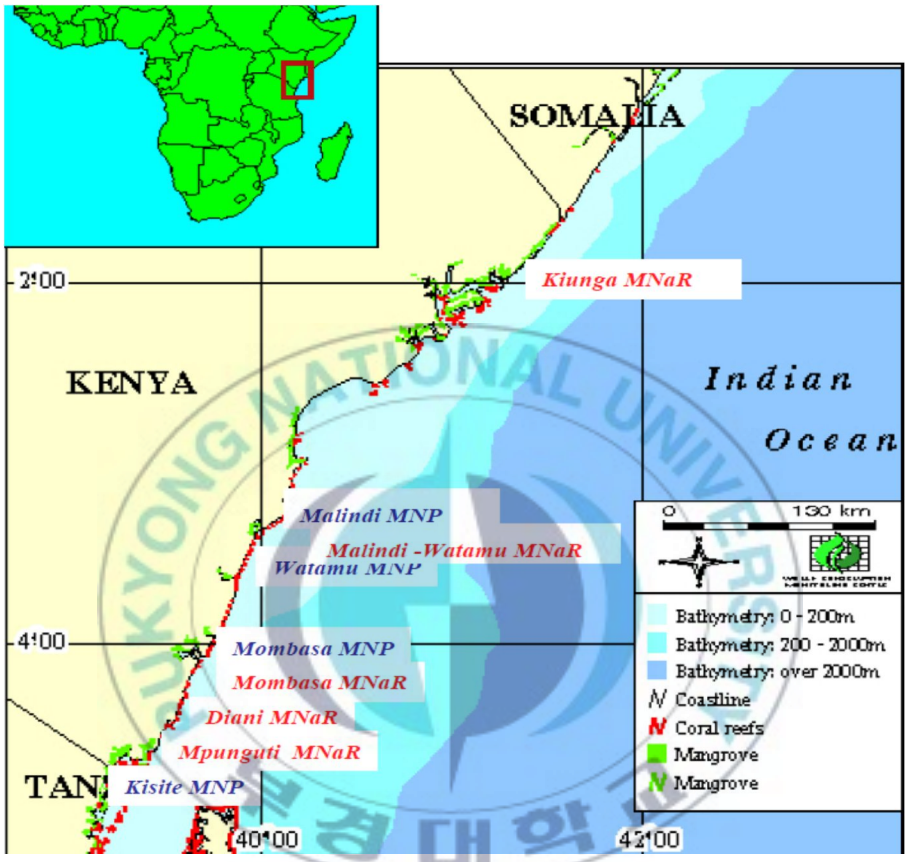

Fig. 1.2. Distribution of coral reefs along the coastline of Kenya and bathymetry outline.

Chapter 2. Ecosystem characteristics of coral reefs.

Coral reefs are one of the ecosystems most threatened by climate variability and change. Reef corals, the building blocks of carbonate reefs, have a restricted thermal tolerance, resulting in 'bleaching' events (loss of symbiotic algae) when sea surface temperatures rise above a given threshold. This has contributed to widespread loss of live coral cover. The restructuring of benthic community composition and has resulted in dire predictions for the future persistence of coral-dominated ecosystems within decadal time scale (McClanahan et al. 2011). There is now a need to understand resultant large-scale implications for other components of the ecosystem, which to date have received limited attention or been the focus of local studies. Assessing ecosystem trends and patterns at regional scales is necessary if informed management choices are to be made, that will mitigate the effects of large-scale climate disturbance. Importantly, there is a need to test key paradigms, such as the ability of no-take areas to enhance recovery from climate change impacts and the potential for herbivorous fish to increase in abundance following coral mortality and functionally compensate for increased algal coverage.

Assessing the importance of local management for conserving coral reefs in the context of global change has been identified as a key research challenge for coral reef scientists. Although there are expectations that no take areas will promote resilience and faster recovery from climate disturbance, site-specific studies suggest this may not be the case and the effectiveness of such management needs to be assessed across regional spatial scales (McClanahan et al. 2002). Coral mortality through climate induced bleaching was particularly severe in the Indian Ocean in 1998, with ~45% of coral cover lost across the region, although the effects were spatially variable. With ever more frequent bleaching events predicted quantitative predictions regarding how fish will respond to future declines in coral cover over large spatial scales are needed to guide regional conservation planning, adaptation and mitigation strategies. The changes reported here represent the combined effects of coral loss in 1998 and any subsequent recovery to 2005 (Mainaa et al. 2008). The greatest declines were apparent through the low latitude island states of Maldives, Chagos and Seychelles. Kenyan and Tanzanian nationally protected sites experienced moderate declines, while

Mauritius and Reunion sustained the smallest declines, and coral cover increased in Kenyan and Tanzanian fished sites (Figure 2.1).

Overfishing is considered one of the three most significant threats to coral reef ecosystems. Exponentially increasing human populations in the tropics have placed enormous demands upon reefs as a food source.

Loss of keystone species, such as predators of echinoderms, through fishing, can lead to major effects on reef processes, such as accretion of calcium carbonate. Ultimately, sustained heavy fishing may lead to loss of entire functional groups of species, resulting in impairment of the potentially important ecosystem functions provided by those groups. Effective management of fishing will require a deeper understanding of the effects of exploitation than we now possess. Research initiatives are underway to examine the responses of fish populations to fishing and general responses to protection from fishing. There are however urgent needs to look beyond fish communities and to consider the entire reef ecosystem.

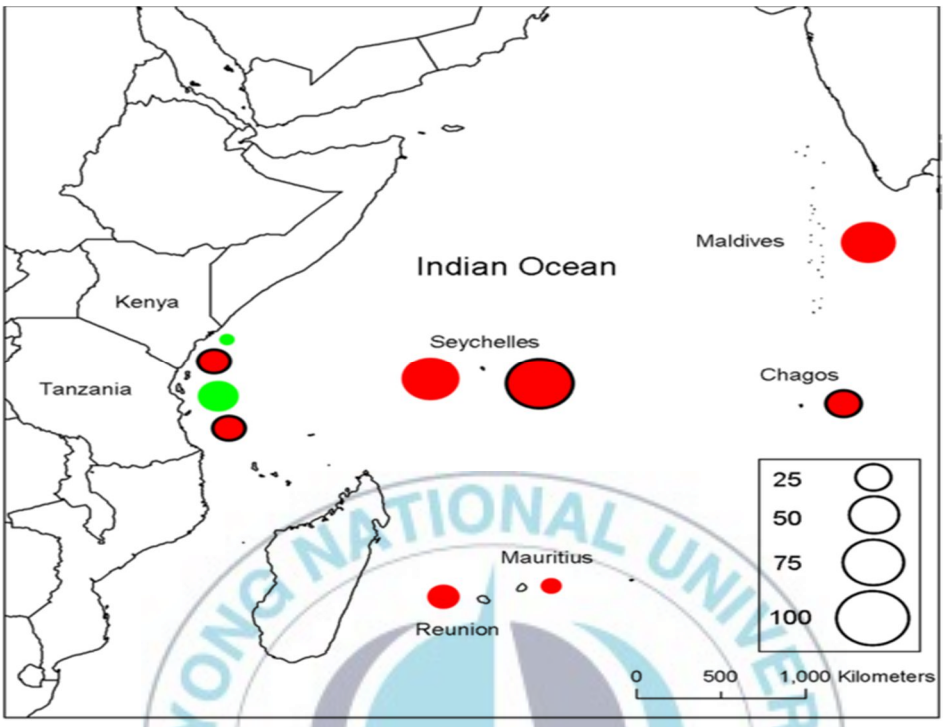

Fig. 2.1. Kenya coral reefs variability.

The red circles represents decreases in coral cover while green circles represent increases in coral cover. Numbers in key (size of bubble) are percent changes between mid-1990s and 2005. Map produced using ESRI data and ArcGIS (Source: climate warming, marine protected areas &oceans integrity of coral reefs ecosystems Journal).

Studies that integrate population and community biology with ecosystem processes will, provide a much better understanding of the effects of biodiversity loss on reef function and will improve our ability to manage these complex systems. A number of studies in Kenyan coral reefs have also demonstrated that, destructive fishing practices in many areas have led to reef degradation and substrate variables, suggest distinct and consistent differences between protected and unprotected reefs (McClanahan 1989). Since the dominant grazers are herbivorous fishes in the protected and sea urchins in the unprotected areas, substrate differences may be attributable to (i) a reduction in finfish, (ii) An increase in sea urchins or (iii) a combination of both changes. Determination of the precise causes requires additional experimentation. Substantial research on finfish and sea-urchin grazing indicates that substrate changes are attributable to changes in the dominant consumers.

Chapter 3. Identification of management objectives and associated attributes for the Kenyan coral reef ecosystem.

3.1. Current stock assessment and fishery management tools

The Kenyan government recognized in Session Paper No. 3 of 1975, "Statement of Future Wildlife Management in Kenya", the need to manage and conserve the country's natural resources. Accordingly, the Fish Industry Act and the Wildlife Management and Conservation Act were enacted by Parliament in 1968 and 1976, respectively. With this legislation, Kenya set a precedent for the rest of Africa. In 1968, the government declared the first marine protected area, and subsequently it continued to put other coral reef areas under a two-tier conservation system that is recognized by law. As a result of this differential management system, coral reefs in Kenya exhibit significant differences in ecological health (Weru 2007). These differences are related to the degree of protection afforded the reef. However, despite delivering benefits in terms of reef health, reef protection measures sometimes impose serious socio-economic costs on fishers forced to relocate or change their life styles.

There is no comprehensive stock assessment undertaken for the Kenya coral reefs ecosystem apart from selected sampling activities for few species undertaken within some selected marine parks along the Kenyan coastline. These selected samplings do not represent the Kenyan coral reef ecosystem as marine protected areas are no take areas. Therefore fish density remains almost same while the exploited areas have not been given much attention. Recent moves to develop management plans on the basis of community consultations are demonstrating the potential for less costly, but nevertheless, effective conservation measures.

As a result of these policies, coral reefs in Kenya can be categorized into three management regimes such as fully protected, partially protected and no protection. Figure 3.1 shows fully protected areas (marine parks), and the partially protected areas (marine national reserves) adjacent to each other. Marine protected areas in Kenya are Malindi National Park (6.3 km^2), Watamu National Park (32 km^2), (Mombasa National Park (10 km^2), and Kisite National Park (28 km^2), all of which are enclosed within the marine reserves (McClanahan 2011).

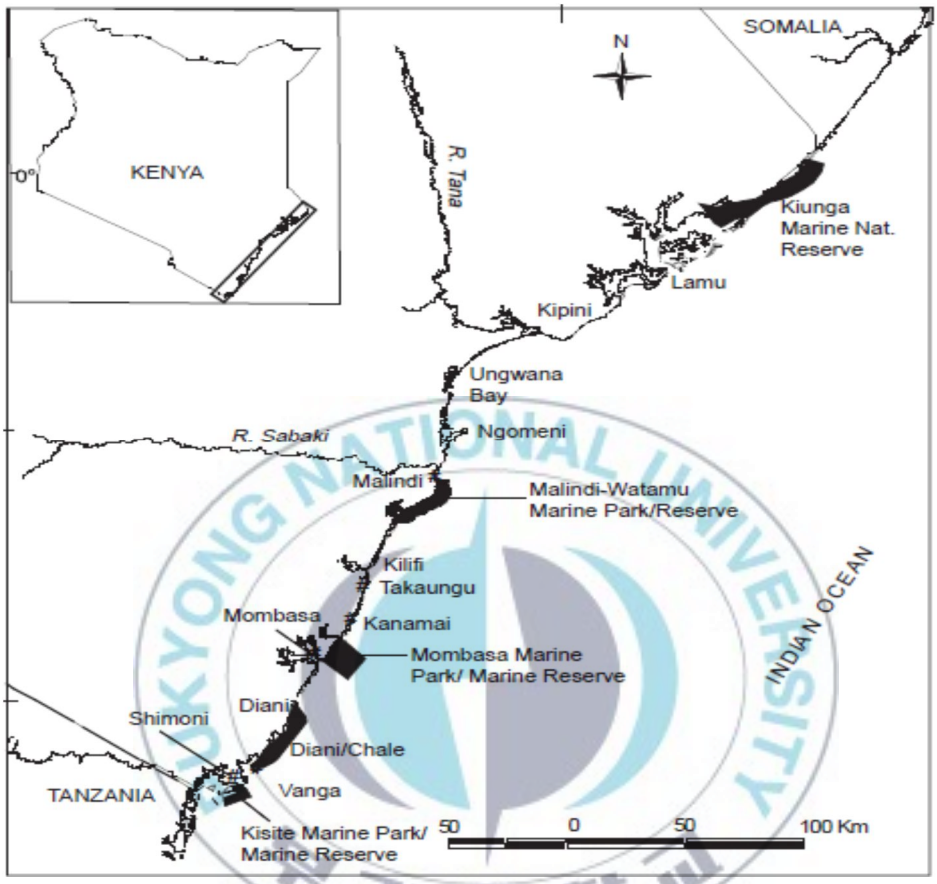

Fig. 3.1. Fully and partially protected areas for the Kenyan coral reef ecosystem (Marine parks are fully protected, but marine reserves are partially protected).

Usually, marine protected areas are smaller in size than marine national reserves. The following are marine national reserves in Kenya with their respective sizes in square kilometers: Kiunga Marine National Reserve (600 km^2), Malindi-Watamu Marine National Reserve (177 km^2), Mombasa Marine National Reserve (200 km^2), Diani Marine National Reserve (75 km^2), and Mpunguti Marine National Reserve (11 km^2).

(a) Fully protected

Fully protected areas are only limited within Marine National Parks, of which there are four. The park is usually the core area consisting of a reef lagoon, reef flat, reef edge and slope, in a (usually) larger reserve. Within these parks, no extractive use is allowed, with or without a license, and the Wildlife Act takes precedence over other policies or legislation. For purposes of research and education, samples may be collected with the authority of the Office of the President in collaboration with the Kenya Wildlife Service (KWS).

(a) Partially protected

These are otherwise referred to as Marine National Reserves, of which there are five. These reserves act as buffer zones to marine parks and as multiple use areas. Harvesting in terms of fishing and collection of other marine organisms is allowed albeit with a license from Fisheries Department. Only traditional harvesting techniques (mostly fishing traps made from coconut palm fronds and straw, locally known as madema or uzio) as well as the universally known hook-and-line are permitted. Collection of sea cucumber and aquarium fish species is also allowed under license. Tourism activities, such as sport fishing, scuba diving and other water sports are allowed at a nominal fee (Cinner et al. 2010).

Both Acts relating to fisheries and wildlife prohibit the use of destructive harvesting methods, such as dynamite fishing, seine netting and coral mining.

(b) No protection

This category applies to coral reef areas outside the designated conservation areas. However, even in these areas, the Fish Industry Act (later revised to Fisheries Act 1991) applies and is enforced by the Fisheries Department.

Although no formal management is in place, destructive fishing methods such as dynamiting and coral mining are prohibited. The Fisheries department may enlist the support of the Kenya Wildlife Service (KWS), the police or the Kenyan Navy in the enforcement of the Act. Nevertheless, due to the lack of control over how and by whom the unprotected resources will be used, there is gross over-exploitation. As a result, these reefs are the most degraded. In addition to their undisputed value in attracting tourists, Kenya's coral reefs are also important for fisheries, with the tourism industry as one of the main markets for fish products. The tourism industry has also created demand for other reef resources, such as corals and shells. Many species are probably being over-exploited and careless collection methods have led to serious habitat damage (Cinner et al. 2008).

3.2. Suggested management objectives

Considering these current management tools in the Kenyan coral reef ecosystem, four management objectives namely sustainability, biodiversity, habitat quality and socio-economy are suggested in this study. These management objectives are suggested together with their associated attributes (Table 3.1). These attributes include: abundance, stock structure, fishing intensity, ecosystem productivity, population resilience and genetic variability for sustainability. Attributes for biodiversity are trophic stability, taxa richness, integrity of functional groups, bycatch and discards. Attributes for habitat quality include; habitat protection, essential habitat damage and discarded wastes. Attributes for socio-economy include; economic considerations, social considerations, cultural considerations, recreational fishery and user conflicts.

Table 3.1. Suggested management objectives and associated attributes for coral reef ecosystems.

Management objectives	Attributes
Sustainability: Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing.	Abundance, stock structure, fishing intensity, ecosystem productivity, population resiliency, genetic variability.
Biodiversity: Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Trophic stability, taxa richness, integrity of functional groups, bycatch and discards.
Habitat quality: Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects.	Habitat protection, essential habitat damage, discarded wastes.
Socio-economy: Increase fisher's economic benefits and job stability.	Economic considerations, social considerations, recreational fishery, user conflicts and cultural considerations.

Chapter 4. Development of indicators to assess risks for coral reef ecosystems.

4.1. Impacts of fishing on fish and coral reef ecosystems

Figure 4.1 shows a flowchart diagram explaining primary, secondary and tertiary impacts of fishing on fish and coral reef ecosystems. Most of the indicators for the four management objectives are derived from this flowchart diagram.

Primary impacts show critical activities that affect fish and ecosystem of coral reefs. Fish habitat damage is caused by fishing activities, which affects sustainability at species level and also at fishery level. Selection of fish size or age is mainly the size of fish that is captured during fishing and it affects sustainability objective at species level. Selection of species is the capture of the target species and the non-target species. This is an indicator for biodiversity objective, which affects biodiversity at fishery level. Coral habitat damage affects habitat quality at fishery level. It's an impact caused by gear and fishermen contact with the corals.

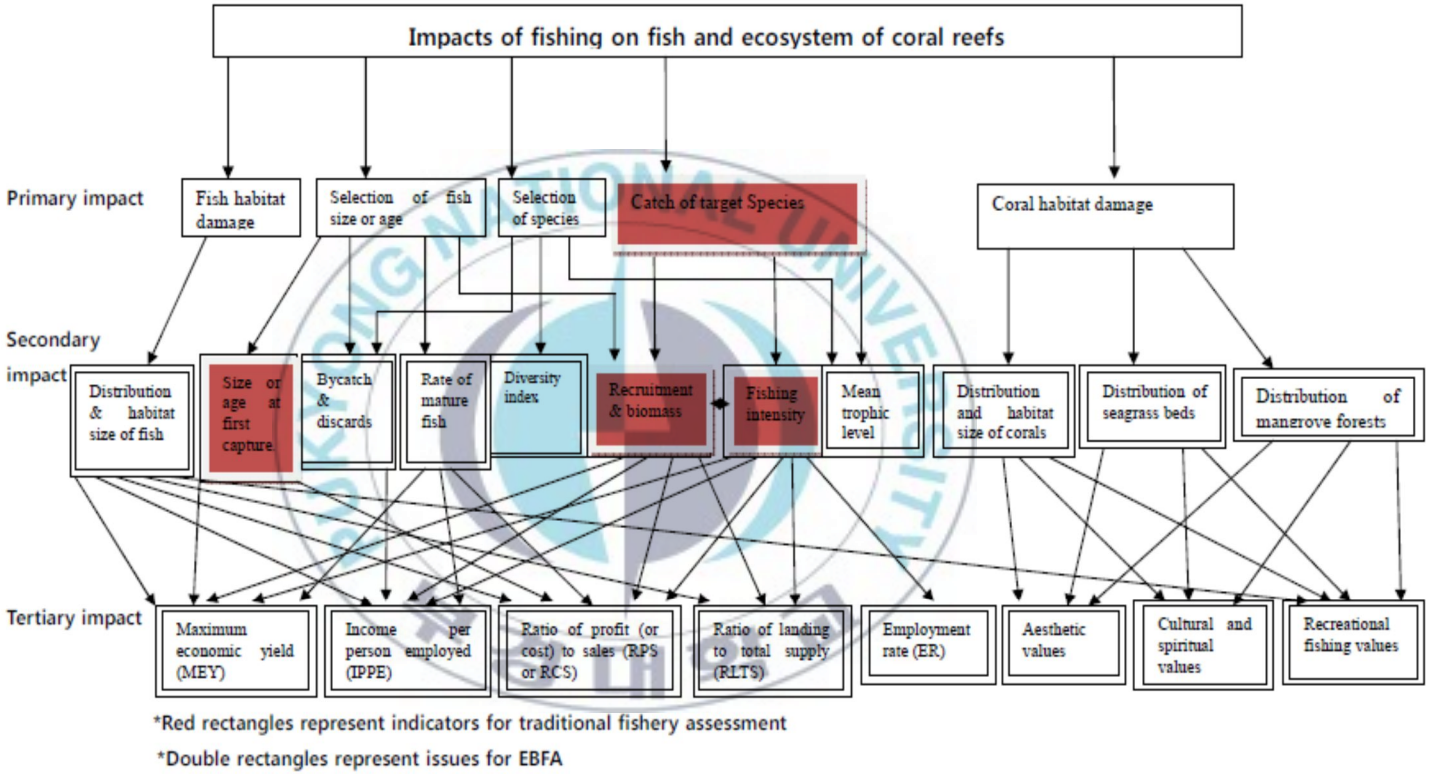

Fig. 4.1. Flowchart diagram showing impacts of fishing on fish and ecosystem of coral reefs.

Secondary impacts are results of primary impacts. The most critical ones include; size or age at first capture, recruitment, biomass, and fishing intensity. They are indicators for sustainability objective, which affect the fishery at the species level. Distribution and habitat size of fish, distribution and habitat size of corals, distribution and habitat size of seagrass beds and distribution of mangrove forests are indicators related with both habitat quality and sustainability. These indicators affect two objectives at species and fishery levels. Bycatch, discards, diversity index, mean trophic level of the community, affect biodiversity at the fishery level, while rate of mature fish affects sustainability at the species level.

Tertiary impacts are results of secondary impacts and falls mainly under the socio-economic objective. They include maximum economic yields, income per person employed, ratio of profit to sales, ratio of landing to total supply and employment rate. These indicators define the economic status of fishing communities. They are business-oriented indicators and determine the levels of income and livelihood status of the fishing communities. Recreational fishing values have some degree of impact on local fishery,

Whereas aesthetic, cultural and spiritual values mainly affect the artisanal fishery and can vary from one community to another.

4.2. Indicators for the Tier 1 and Tier 2 assessments for coral reef ecosystems

4.2.1. Indicators for sustainability

Indicators for sustainability developed in this study are shown in Table 4.1. Relative weights for each indicator were obtained by conducting a series of expert workshops, considering: 1) the importance for achieving the objectives, 2) scientific basis for estimating indicators and reference points, and 3) availability of data and information. Each weight is represented by one to three asterisks. For instance, 'Spawning biomass' was given a weight of three asterisks, and 'Number of spawning population' one asterisk under the sustainability objective (Table 4.1). Then, the number of asterisks was coded with a numerical value: '1' for one asterisk, '2' for two asterisk, and '3' for three asterisks (Zhang et al. 2010).

Table 4.1. Indicators to assess risks for coral reef ecosystems.

Objectives	Attributes	Indicators	Level	Weight
Sustainability	Abundance	Spawning biomass (SB)	S	3
	Fishing intensity	Fishing mortality (F)	S	2
		Annual catch (C)	S	1
	Stock structure	Rate of mature fish (RMF)	S	1
		Spawning potential ratio (SPR)	S	1
		Average length ($\bar{L}$)	S	1
		Age (or length)at first capture (tc)	S	1
	Ecosystem productivity	Mean trophic level of catch (TL_C)	F	1
	Genetic variability	No. of spawning population (SP)	S	1
	Population resiliency	Changes in ratio of coral coverage of fishing area (CC)	S	1
	(Reproduction habitat)	Changes in ratio of seagrass coverage of fishing area (SC)	S	1
		Changes in ratio of mangrove coverage of fishing area (MC)	S	1
Biodiversity	Bycatch and discards	Bycatch or Incidental catch (BIC)	F	2
		Discards (DC)	F	1
	Taxa richness	Shannon-Wiener Diversity Index (DI)	F	1
		No. of species in catch (NS)	F	1
	Trophic stability (Community structure)	Mean trophic level of the community (TL_{CO})	F	1
		Predator/prey in catch (P/P)	F	1
	Integrity of functional groups	Invasive/traditional species in catch (I/T)	F	1
Habitat quality	Habitat protection	MPA's or No take areas (MP)	S	3
		MNR's or Low use areas (MN)	S	2
	Essential habitats damage	Pollution of spawning and nursery areas (PA)	F	1
		Lost fishing gear (FG)	F	1
		Runoffs of fresh water (RF)*	F	1
		Impacted/pristine of corals(I/PC)	F	1
		Impacted/ pristine of mangroves (I/PM)	F	1
		Impacted/ pristine of seagrass (I/PS)	F	1
	Discarded wastes	Discarded wastes from fishing vessels (DW)	F	1
		Sewage loadings (SL)*	F	1

Socio-economic benefit	Economic considerations	Income per person employed (IPPE)	F	2
		Sale/cost (RSC)	F	1
		Price of fish (PF)	F	1
		Fuel cost (FC)	F	1
		Profit/sale (RPS)	F	1
		Boat ramps (BR)**	F	1
		Trophy fish (TF)**	F	1
		Permit cost (PC)**	F	1
	Social considerations	Employment rate (ER)	F	1
		Job stability (JST)	F	1
		Job satisfaction (JSA)	F	1
	User conflicts	Commercial/total catch (C/T)	F	1
		Recreational/total catch (R/T)	F	1
		Subsistence/total catch (S/T)	F	1
	Cultural considerations	Traditional cultural satisfaction (CS)	F	1

* Indicators independent of fishing activities

** Indicators only for the recreational fishery

The same indicators across Tier 1 and Tier 2 assessments can be weighted differently, depending on the scientific basis and availability of data and information. However, we used the same weights for the two assessments. With reference to Table 4.1, the following indicators were weighted according to their respective objectives as follows; 'Spawning biomass' was assessed risk at species level with a weight of '3'. 'Fishing mortality' was assessed risk at species level with a weight of '2'. 'Rate of mature fish' was assessed risk at species level with a weight of '1'. 'Spawning potential ratio' was assessed risk at species level with a weight of '1'. 'Average length' was assessed risk at species level with a weight of '1'. 'Age (or length) at first capture' was assessed risk at species level with a weight of '1'. 'Mean trophic level of catch' was assessed risk at fishery level with a weight of '1'. 'Number of spawning population' was assessed risk at species level with a weight of '1'. 'Changes in ratio of coral coverage of fishing area', 'changes in ratio of seagrass coverage of fishing area' and 'changes in ratio of mangrove coverage of fishing area' were all assessed risk at species level with a weight of '1' respectively.

4.2.2. Indicators for biodiversity

Bycatch/incidental catches (BIC) and discards (DC) are the most important indicators of this management objective. Bycatch refers to the non-target catches that are not discarded but consumed. Coral reef fisheries has for a long time not differentiated bycatch from target species. This is because most fishermen collect everything for house hold consumption.

'Bycatch or incidental catch' was assessed risk at fishery level with at a weight of '2'. This is because most of the protected species and the vulnerable species are the most consumed in plenty, while 'discards' was assessed risk at fishery level with a weight of '1'. 'Shannon-Wiener Diversity Index' was assessed risk at fishery level with a weight of '1'. 'Number of species in catch' was assessed risk at fishery level with a weight of '1'. 'Mean trophic level of the community' was assessed risk at fishery level with a weight of '1'. 'Invasive/traditional species' was assessed risk at fishery level with a weight of '1'. 'Predator/prey in catch' and 'Invasive species/traditional species in catch' indicators were all assessed risk at fishery level with a weight of '1' respectively.

4.2.3. Indicators for habitat quality

Habitat protection is very critical objective since it determines the survival and status of the ecosystem. The other three management objectives may depend on the state of habitat quality. ‘Marine protected or No take areas’ was assessed risk at species level with a weight of ‘3’. ‘Marine national reserves or low use areas’ was assessed risk at species level with a weight of ‘2’. ‘Pollution of spawning and nursery areas’ was assessed risk at fishery level with a weight of ‘1’.

‘Lost fishing gear’ indicator was assessed risk at fishery level with a weight of ‘1’, ‘Runoffs of fresh water’ was assessed risk at fishery level with a weight of ‘1’. ‘Impacted/pristine of corals’ was assessed risk at fishery level with a weight of ‘1’, ‘Impacted/pristine of seagrass’ was assessed risk at fishery level with a weight of ‘1’.

‘Impacted pristine of mangroves’ was assessed risk at fishery level with a weight of ‘1’ and ‘Discarded wastes from fishing vessels’ indicator was assessed risk at fishery level with a weight of ‘1’. All these indicators have to be constantly checked to maintain checks and balances of habitat quality management objective.

4.2.4. Indicators for socio-economy

Socio-economy management objective is very important for the coral reef ecosystems. This objective has the following indicators which determine the socio-economic and cultural considerations of the coral reef fishery. 'Commercial/total catch (C/T)' determines the catches landed. When this indicator shows high catches, fishing effort can be regulated.

Low catches landed can lead to increased fishing effort. 'Commercial/total catch' indicator was assessed risk at fishery level with a weight of '1'. 'Profit/sale (RPS)' and 'Sale/cost (RSC)' are indicators that show business trends. These indicators show the rate of investments and the income in terms of profit and loss. These indicators were all assessed risk at fishery level with a weight of '1' respectively. 'Income per person employed' was assessed risk at fishery level with a weight of '1'. 'Price of fish' and 'Fuel cost' indicators are rates of profit per person and operational costs that vary depending on investment magnitude. 'Price of fish' and 'Fuel cost' indicators were all assessed risk at fishery level with a weight of '1'. 'Employment rate', 'Job stability' and 'Job satisfaction' indicators were all assessed risk at fishery level with a weight of '1' respectively. 'Boat

ramps', 'Trophy fish' and 'Permit cost' indicators were all assessed risk at fishery level with a weight of '1' respectively.

Cultural considerations are important in all fishing communities. They determine the participation of communities in the management of coral reef fisheries depending on their satisfaction. 'Traditional cultural satisfaction' indicator was assessed risk at fishery level with a weight of '1'. This implies that if risks of indicators increase, then species or fisheries in the coral reefs ecosystem will be dangerously affected and therefore proper management tools must be applied.

4.3. Indicators for the Tier 2 assessment of coral reef ecosystems

All the indicators in the Tier 2 assessment are the same ones used in Tier 1 for the four management objectives in the ecosystem-based fisheries assessment (EBFA). Indicators for sustainability are spawning biomass (SB), fishing mortality (F), rate of mature fish (RMF), spawning potential ratio (SPR), age (or length) at first capture (tc), and average length ($\bar{L}$), mean trophic level of catch (TL_C), number of spawning population (SP), changes in ratio of coral coverage of fishing area (CC), changes in ratio of seagrass

coverage of fishing area (SC), and changes in ratio of mangrove coverage of fishing area (MC).

Indicators for biodiversity are bycatch or incidental catch (BIC), discards (DC), Shannon-wiener diversity index (DI), number of species in catch (NS), Mean trophic level of the community (TLc_O), predator/prey in catch (P/P) and invasive/traditional species in catch (I/T).

Indicators for habitat quality are marine protected areas or no take areas (MP), marine national reserves or low use areas (MN), pollution of spawning and nursery areas (PA), lost fishing gear (FG), runoffs of fresh water (RF), impacted/pristine of corals (I/PC), impacted/pristine of mangroves (I/PM), impacted/pristine of seagrass (I/PS), discarded wastes from fishing vessels (DW) and sewage loadings (SL).

Indicators for socio-economy in Tier 2 assessment are income per person employed (IPPE), sale/cost (RSC), price of fish (PF), fuel cost (FC), profit/sale (RPS), boat ramps (BR), trophy fish (TF), permit cost (PC), employment rate (ER), job stability (JST), job satisfaction (JSA), commercial/total catch (C/T), recreational/total catch (R/T), subsistence/total catch (S/T) and traditional cultural satisfaction (CS).

Chapter 5. Development of target and limit reference points for the coral reef ecosystems.

5.1. Assessment of risks using reference points

Both target and limit reference points for each indicator were established in this study as shown in Figure 5.1. The target reference point in this application corresponds to a state of each indicator that is considered desirable, while the limit reference point is defined as the limit beyond which the state of each indicator is not considered desirable. Species were assigned a status for each indicator to denote risk. The risk score is calculated for each indicator as,

$$RS_i = \frac{I_{target} - I_i}{I_{target} - I_{limit}} + 1$$

where, RS_i is the risk index for indicator i, I_i, I_{traget}, and I_{limit} are estimated, target and limit values for indicator i, respectively. If the calculated risk index of the indicator was less than zero, then a score of '0' was assigned. If it was greater than three, then a score of '3' was assigned.

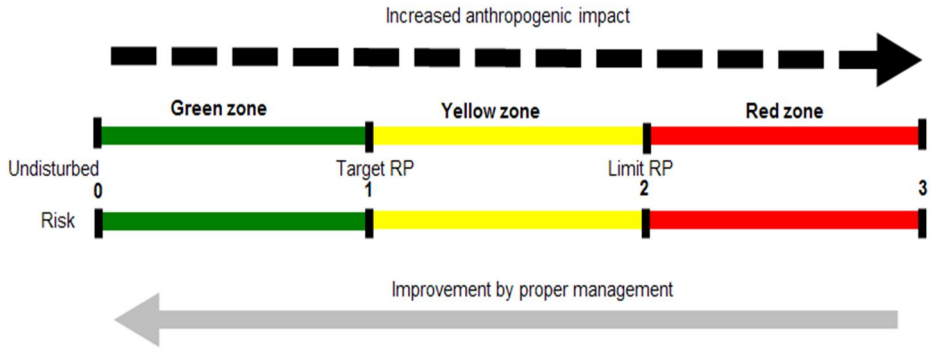

Fig. 5.1. Reference point (RP) and risk indices for the ecosystem-based assessment approach (Revised from Zhang et al. 2009).

Figure 5.1 shows three levels of risk indices as follows; The green zone shows the 'Better than target' reference point and denotes risk indices between ('0' and '1'). The yellow zone shows 'Between target and limit' reference point and denotes risk indices between ('1.0' and '2.0'). The red zone shows 'Beyond limit' reference point and denotes risk indices between ('2.0' and '3.0'). Risk indices between '0' and '1' represents proper management, risk indices between '1.0' and '2.0' represents moderate management, while risk indices between '2.0' and '3.0' represents open access without proper management.

5.2. Target and limit reference points for the Tier 2 assessment for the Kenyan coral reef ecosystem.

5.2.1. Target and limit reference points for indicators of sustainability

Appendix V shows the targets and limit reference points of sustainability for the Tier 2 assessment. Tier 2 approach requires quantitative data for indicators assessment. The ecosystem-based fisheries assessment (EBFA) identifies several critical indicators including spawning biomass (SB) or catch per unit effort (CPUE) as the most critical. Assessment is divided into seven categories as follows; for 'Better than target', two reference points ('0' and '0.5'), for 'Between target and limit', three reference points ('1.0', '1.5', and '2.0'), for 'Beyond limit', two reference points ('2.5' and '3.0'). Catch per unit effort (CPUE) is assessed based on factors of data availability, standardization and catch trends of CPUE. 'Spawning potential ratio (SPR)' is assessed based on the factor of spawning intensity of various fish species present in the coral reef ecosystem. 'Rate of mature fish in catch (RMF)' is assessed based on the percentage of mature fish present in catch. 'Average length ($\bar{L}$)' is assessed based on the mean mature length of the catch.

‘Changes in ratio of coral coverage of fishing area (CC)’ is assessed based on the percentage change of area in coral cover of the fishing area in the coral reef ecosystem compared with virgin coral cover area before fishing started. ‘Changes in ratio of seagrass coverage of the fishing area (SC)’ is assessed based on the percentage change of area of seagrass cover of the fishing area compared with virgin seagrass cover area before fishing started. ‘Changes in ratio of mangrove coverage of fishing area (MC)’ is assessed based on the percentage change in area of mangrove cover of the fishing area compared with virgin mangrove area cover before fishing started. ‘Number of spawning population’ indicator is assessed based on the number of spawning populations present in the coral reef ecosystem. ‘Fishing effort’ is assessed based on the number of fishermen, number of gears, fishing hours, fishing gear efficiency and fishing gear capacity in the coral reef ecosystem.

5.2.2. Target and limit reference points for indicators of biodiversity

Appendix VI shows all the targets and limit reference points for biodiversity. Biodiversity is one of the most important objectives in the Tier 2 assessment and is divided into seven categories as follows; for ‘Better than target’, two

reference points (‘0’ and ‘0.5’), for ‘Between target and limit’, three reference points (‘1.0’, ‘1.5’, and ‘2.0’), for ‘Beyond limit’, two reference points (‘2.5’ and ‘3.0’). Indicators used in the ecosystem-based fisheries assessment (EBFA) for biodiversity in the Tier 2 include; ‘Mean trophic level of the community (TL_{CO})’ and is assessed based on the ratio of herbivorous fish species to carnivorous fish species in catch and ecosystem. ‘Number of species composition in catch (NS)’ is assessed based on the number of different types of species present in the catch. ‘Bycatch or incidental catches (BIC)’ is assessed based on the percentage or quantity of the non-target species present in the catch. ‘Discards (DC)’ indicator is assessed based on the quantity of discarded fish from the catch.

5.2.3. Target and limit reference points for indicators of habitat quality

Appendix VII shows targets and limit reference points for habitat quality in the Tier 2, assessment is divided into seven categories in the same manner with sustainability and biodiversity objectives. Habitat quality has several indicators used in ecosystem-based fisheries assessment (EBFA), these indicators are assessed based on the following factors for each indicator. ‘Impacted/pristine of corals (I/PC)’ is assessed based on the level of impacts

caused on the corals from fishing activities in the coral reef ecosystem. 'Impacted/pristine of seagrass (I/PS)' is assessed based on the level of impacts caused on the seagrass from fishing activities in the coral reef ecosystem. 'Impacted/pristine of mangroves (I/PM)' is assessed based on the level of impacts caused on the mangroves from fishing activities.

'Pollution of spawning and nursery areas (PA)' is assessed based on the level of pollution in the spawning and nursery areas from fishing activities. 'Lost fishing gear (FG)' is assessed based on the amount or quantity of lost fishing gear reported in the coral reef ecosystem. 'Runoffs of fresh water (RF)' is assessed based on the amount of runoffs occurring in the coral reef ecosystem. 'Discarded wastes from fishing vessels (DW)' is assessed based on the quantity of discarded wastes occurring in the coral reef ecosystem from fishing vessels. 'Sewage loadings (SL)' is assessed based on the quantity of sewage loadings occurring in the coral reef ecosystem. 'Marine protected or No take areas (MP)' is assessed based on the total area protected in the coral reef ecosystem where fishing activities are prohibited. 'Marine national reserves or Low use areas (MN)' is assessed based on the total area in the coral reef ecosystem where fishing activities are allowed on limited scale.

5.2.4. Target and limit reference points for indicators of socio-economy

Appendix VIII shows targets and limit reference points for socio-economy. Socio-economy management objective has always been very sensitive to coastal fishing communities. This objective has indicators used in ecosystem-based fisheries assessment (EBFA) that shows the welfare and economic status of fishing communities. This helps managers to design better management tools acceptable to fishing communities. Fishing communities accept measures when they tend to be doing well economically and tend to oppose almost all measures when they perform poorly economically.

Target and limit reference points for socio-economy in the Tier 2 assessment is divided into seven categories in the same manner with sustainability, biodiversity and habitat quality objectives. 'Income per person employed (IPPE)' indicator is assessed based on the income per fisherman compared with the living standard. 'Sale/cost is assessed based on the ratio of sales to cost of fishing'. 'Price of fish' is assessed based on the price of target and non target species in the market. 'Fuel cost' is assessed based on the cost of fuel used or consumed for fishing. 'Profit/sale' is assessed based on the ration of profit to sales form he fishery. 'Boat ramps'

is assessed based on the level of use by the fishery. ‘Trophy fish’ is assessed based on the frequency of capture of big size fish of the target species. ‘Permit cost (PC)’ is assessed based on the total cost for fishing permits. ‘Employment rate (ER)’ is assessed based on the number of fishermen and actual fishing days occurring in the coral reef ecosystem. ‘Job stability (JST)’ is assessed based on the duration taken in fisheries activities before changing to other income generating activities. ‘Job satisfaction (JSA)’ is assessed based on the level of satisfaction expressed by those engaged in fisheries activities in the coral reef ecosystem. ‘Commercial catch’ is assessed based on the total catch sold from the harvests. ‘Subsistence/total catch (S/T)’ is assessed based on the quantity of house-hold catch trends. ‘Traditional cultural satisfaction (CS)’ is assessed based on the level of satisfaction expressed by the local community engaged in fishing activities in the coral reefs ecosystem.

Chapter 6. Assessment of risk scores to each indicator of the Kenyan coral reef ecosystem.

6.1. Major fisheries and fish species by fishing gears for coral reef ecosystem of Kenya

Major fisheries were identified based on the percentage landings as follows; gillnet fishery had blacktip reef shark 35.3 % catch of the fishery, manta rays 32.4% catch of the fishery, Indian squid 19.0 % catch of the fishery and ornate spiny lobster 13.3% catch of the fishery. Hook and line fishery had spotcheeck emperor 26.9% catch of the fishery, common octopus 25.8% catch of the fishery, humphead snapper 25.4 % catch of the fishery and honeycomb grouper 21.9% catch of the fishery (Ministry of Fisheries Development annual report 2011).

Traditional trap fishery had rabbit fish 52.3 % catch of the fishery and parrotfish 47.7 % catch of the fishery. Purse seine fishery had striped bonito 55.0 % catch of the fishery and blacktip sardinella 45.0 % catch of the fishery. The above total catch constitutes 51% of the total coral reef catch, while other reef fishes and fisheries constitute 49% as shown in Table 6.1.

Table 6.1. Major fisheries and fish species by fishing gears of the Kenyan coral reef ecosystem.

Type of fishery	Target species	Scientific name	Catch in kg (%)
Gillnet fishery	Blacktip reef shark	*Carcharhinus melanopterus*	229,020 (35.3)
	Manta rays	*Manta alfredi*	210,213 (32.4)
	Indian squid	*Uroteuthis duvaucelii*	122,980 (19.0)
	Ornate spiny lobster	*Panulirus ornatus*	86,666 (13.3)
Subtotal			648,879 (100)
Hook and line fishery	Spotcheeck emperor	*Lethrinus rubrioperculatus*	156,606 (26.9)
	Common octopus	*Octopus vulgaris*	150,492 (25.8)
	Humphead snapper	*Lutjanus sanguineus*	148,216 (25.4)
	Honeycomb grouper	*Epinephelus merra*	127,728 (21.9)
Subtotal			583,042 (100)
Traditional trap fishery	Rabbit fish	*Siganus canaliculatus*	220,575 (52.3)
	Parrotfish	*Scarus ghobban*	201,116 (47.7)
Subtotal			421,691 (100)
Purse seine fishery	Striped bonito	*Sarda orientalis*	227,404 (55.0)
	Blacktip sardinella	*Sardinella melanura*	186,572 (45.0)
Subtotal			413,976 (100)
Total			**2,067,588 (51.0)**
Other reef fisheries			**1,993,414 (49.0)**
Annual total catch			**4,061,002 (100)**

6.2. Assessment for the twelve species of the Kenyan coral reef ecosystem by the Tier 2 approach.

Kenyan coral reef ecosystem has twelve species that were assessed by the Tier 2 approach for the four fisheries as follows; Gillnet fishery has four species namely; Blacktip reef shark, manta rays, indian squid and ornate spiny lobster. Objective risk indices for all the fisheries were calculated using the formula $ORI = \frac{\sum_{i=0}^{n} I_i W_i}{\sum_{i=1}^{n} W_i}$ Where "I_i" is the score for indicator "i" with given associated reference points. "w" is the weight factor for indicator "i" which is represented by the number of asterisks. The "n" in the equation is the number of indicators. Separate objective Risk indices (ORI) are calculated for each species respectively. These are ORI_S for sustainability, ORI_B for biodiversity, ORI_H for habitat quality, ORI_E for socio-economy. Indicators risk zones for the Kenyan coral reef ecosystem were classified into four objectives for the 12 species as assessed by the Tier 2 approach (Table 6.2). Sustainability has 10.1 % of the indicators in the desirable green zone.

Table 6.2. Risk zones for number of indicators in the Kenyan coral reef ecosystem.

Objective	Number of indicators in the green zone	Number of indicators in the yellow zone	Number of indicators in the red zone
Sustainability	10 (10.1%)	78 (78.8 %)	11 (11.1%)
Biodiversity	54 (64.2%)	26 (31 %)	4 (4.8 %)
Habitat quality	4 (30.8 %)	7 (53.8 %)	2 (15.4 %)
Socio-economy	81 (45%)	97(53.9)	2 (1.1%)
Total	149 (39.6 %)	208 (55.3%)	19 (5.1 %)

The yellow zone has 78.8 % of the indicators and the red zone has 11.1 % of the indicators.

Biodiversity has 64.2 % of the indicators in the desirable green zone, the yellow zone has 31.0 % of the indicators and the red zone has 4.8 % of the indicators. Habitat quality has 30.8 % of the indicators in the desirable green zone, the yellow zone has 53.8 % of the indicators and the red zone has 15.4 % of the indicators. Socio-economy has 45.0 % of the indicators in the desirable green zone, the yellow zone has 53.9 % of the indicators and the red zone has 1.1 % of the indicators.

Overall the Kenyan coral reef ecosystem has 39.6 % of the indicators in the desirable green zone, 55.3 % in the yellow zone and 5.1 % in the red zone.

Gillnet fishery has species; Blacktip reef shark with risk indices '1.67', '1.29', '1.30' and '0.93' for sustainability, biodiversity, habitat quality and socio-economy, respectively (Figure 6.1). Manta ray has risk indices '1.60', '1.29', '1.30' and '1.13' for all the objectives, respectively. Indian squid has risk indices '1.68', '1.29', '1.30' and '1.03', respectively for all the objectives. Ornate spiny lobster has risk indices '1.36', '1.07', '1.30' and '0.83', respectively for all the objectives.

Hook and line fishery has four species namely; Spotcheeck emperor, common octopus, humphead snapper and honeycomb grouper. Spotcheeck emperor has risk indices '1.59', '0.79', '1.25' and '1.10' for sustainability, biodiversity, habitat quality and socio-economy, respectively. Common octopus has risk indices '1.68', '0.57', '1.25' and '0.66' for sustainability, biodiversity, habitat quality and socio-economy, respectively. Humphead snapper has risk indices '1.50', '0.57', '1.25' and '0.67' for sustainability, biodiversity, habitat quality and socio-economy, respectively. Honeycomb grouper has risk indices '1.32', '0.57', '1.25' and '1.10' for sustainability, biodiversity, habitat quality and socio-economy, respectively.

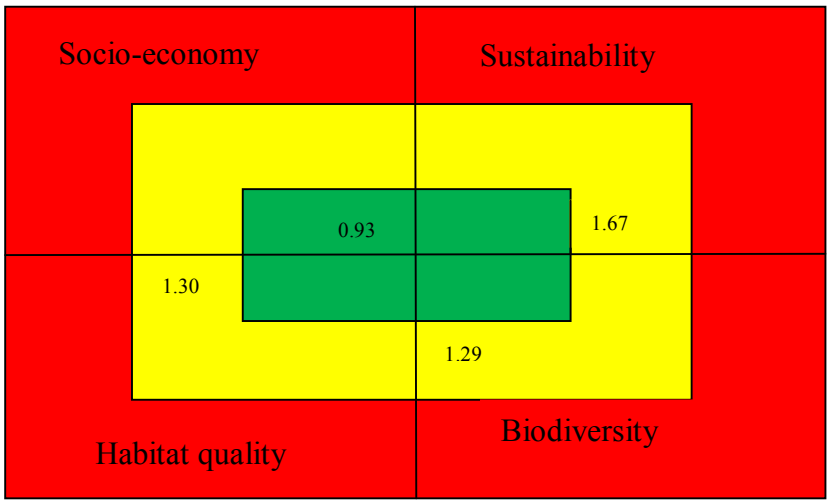

Fig. 6.1. Objective risk diagram for blacktip reef shark by the gillnet fishery in the Kenyan coral reef ecosystem.

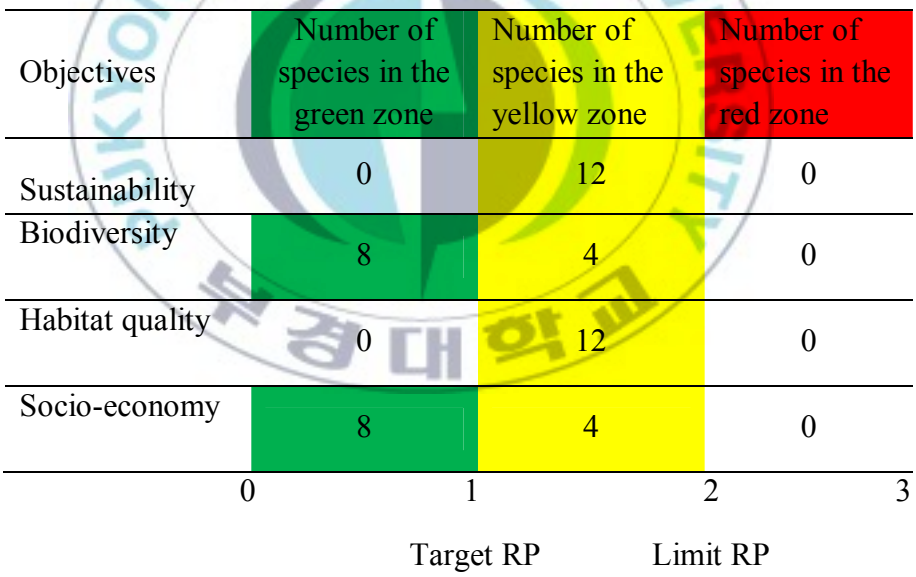

Fig. 6.2. Number of species by risk zones diagram for four objectives in the Kenyan coral reef ecosystem.

Traditional trap fishery has two species rabbit fish and parrotfish that were assessed for objective risk indices. Rabbit fish has risk indices ‘1.54’, ‘0.50’, ‘1.35’ and ‘0.90’, for sustainability, biodiversity, habitat quality and socio-economy, respectively. Parrotfish has risk indices ‘1.54’, ‘0.50’, ‘1.35’ and ‘0.97’, for sustainability, biodiversity, habitat quality and socio-economy, respectively.

Purse seine fishery has two species namely; Striped bonito and blacktip sardinella. Striped bonito has risk indices ‘1.00’, ‘0.79’, ‘1.20’ and ‘0.60’, for sustainability, biodiversity, habitat quality and socio-economy, respectively. Blacktip sardinella has risk indices ‘1.18’, ‘0.79’, ‘1.20’ and ‘0.79’.

Sustainability has all the twelve species with risk indices in the yellow zone for all the fisheries (Figure 6.2). Biodiversity has eight species with risk indices in the desirable green zone and four species with risk indices in the yellow zone. Habitat quality has all the twelve species with risk indices in the yellow zone. Socio-economy has eight species with risk indices in the desirable green zone and four species with risk indices in the yellow zone. Most of the fisheries have risk indices in the yellow zone for the twelve species as classified by objectives. No objective has species with risk

indices in the red zone. Corrective management measures are required for objectives with risk indices in the yellow zone to improve on their status for all the fisheries.

Objective risk indices for twelve species assessed by the Tier 2 approach for the Kenyan coral reef ecosystem were summarised as shown in Table 6.3. Sustainability has no species risk index in the desirable green zone, 100 % of the species risk indices in the yellow zone and no species risk index in the red zone. Biodiversity has 66.7 % of the species risk indices in the desirable green zone, 33.3 % of the species risk indices in the yellow zone and no risk index in the red zone. Habitat quality has 100 % of the species risk indices in the yellow zone and no species risk indices in the green and red zones. Socio-economy has 66.7 % of the species risk indices in the desirable green zone, 33.3 % of the species risk indices are in the yellow zone and no species risk index in the red zone.

Table 6.3. Number of species by risk zones for four objectives for the Kenyan coral reef ecosystem.

Objectives	Number of species in the green zone	Number of species in the yellow zone	Number of species in the red zone
Sustainability	0 (0 %)	12 (100%)	0 (0%)
Biodiversity	8 (66.7%)	4 (33.3%)	0 (0%)
Habitat quality	0 (0%)	12 (100%)	0 (0%)
Socio-economy	8 (66.7%)	4 (33.3%)	0 (0%)
Total	16 (33.3%)	32 (66.7%)	0 (0%)

Chapter 7. Evaluation of coral reef fisheries of the Kenyan coral reef ecosystem based on estimated risk indices.

7.1. Species Risk Indices of each fishery in the Kenyan coral reef ecosystem assessed by the Tier 2 approach

Species risk indices for the Kenyan coral reef ecosystem were calculated from objective risk indices for the 12 species. In this study we assumed $\lambda_S = \lambda_B = \lambda_H = \lambda_E = 0.25$ for calculating SRI′s from ORI′s for all the species as follows;

$$SRI = \lambda_S ORI^{S} + \lambda_B ORI^{B} + \lambda_H ORI^{H} + \lambda_E ORI^{E}$$

Species Risk Indices for the gillnet fishery

The gillnet fishery had four species namely; Blacktip reef shark, manta rays, Indian squid and ornate spiny lobster. The four species of this fishery were assessed by the Tier 2 approach in the Kenyan coral reef ecosystem as shown in Table 7.1. All the four species have risk indices that fall in the yellow zone as shown in Figure 7.1.

Table 7.1. Species Risk Indices by fishery assessed by the Tier 2 approach in the Kenyan coral reef ecosystem.

Gillnet fishery

Species	Species Risk Indices
Blacktip reef shark	1.30
Manta rays	1.33
Indian squid	1.33
Ornate spiny lobster	1.14
FRI	1.28

Hook and line fishery

Species	Species Risk Indices
Spotcheeck emperor	1.18
Common octopus	1.04
Humphead snapper	1.00
Honeycomb grouper	1.06
FRI	1.07

Traditional trap fishery

Species	Species Risk Indices
Rabbit fish	1.09
Parrotfish	1.09
FRI	1.09

Purse seine fishery

Species	Species Risk Indices
Striped bonito	0.90
Blacktip sardinella	0.97
FRI	0.94

Species Risk Indices for the hook and line fishery

The hook and line fishery had four species namely; Spotcheeck emperor, common octopus, humphead snapper and honeycomb grouper. The four species of this fishery were assessed by the Tier 2 approach in the Kenyan coral reef ecosystem as shown in Table 7.1. All the four species have risk indices that fall in the yellow zone (Figure 7.1).

Species Risk Indices for the traditional trap fishery

The traditional trap fishery had two species namely; Rabbit fish and parrotfish. This two species of this fishery were assessed by the Tier 2 approach in the Kenyan coral reef ecosystem (Table 7.1). All the two species have risk indices that fall in the yellow zone as shown in Figure 7.1.

Gillnet fishery

Species	Green zone	Yellow zone	Red zone
Blacktip reef shark		1.30	
Manta rays		1.33	
Indian squid		1.33	
Ornate spiny lobster		1.14	

Hook and line fishery

Species			
Spotcheeck emperor		1.18	
Common octopus		1.04	
Humphead snapper		1.00	
Honeycomb grouper		1.06	

Traditional trap fishery

Species			
Rabbit fish		1.09	
Parrotfish		1.09	

Purse seine fishery

Species			
Striped bonito	0.90		
Blacktip sardinella	0.97		

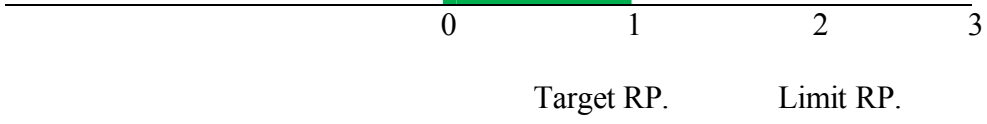

Figure 7.1 Species risk diagrams by fishery assessed by the Tier 2 approach in the Kenyan coral reef ecosystem.

Species Risk Indices for the purse seine fishery

Purse seine fishery had two species namely; Striped bonito and blacktip sardinella. This two species of this fishery were assessed by the Tier 2 approach in the Kenyan coral reef ecosystem (Table 7.1). All the two species have risk indices that fall in the desirable green zone (Figure 7.1).

Two species fall in the desirable green zone and ten species that were assessed fall in the yellow zone. Corrective management systems should be put in place for the ten species to reduce species risk indices.

7.2. Fishery Risk Indices and Ecosystem Risk Index for the Kenyan coral reef ecosystem.

Fisheries risk indices were calculated from the following formula.

$FRI = \frac{\sum C_i \ SRI_i}{\sum \ C_i}$, where C_i is catch instead of $FRI = \frac{\sum B_i \ SRI_i}{\sum \ B_i}$, where B_i is biomass. This is because data for biomass were not available.

Twelve species risk indices were used to calculate fishery risk indices for the four fisheries in the Kenyan coral reef ecosystem as shown in Table 7.2. The four fisheries assessed by the Tier 2 approach are; Gillnet fishery, hook and line, traditional trap fishery and purse seine fishery. Three fisheries namely; the gillnet fishery, hook and line fishery and traditional trap have risk indices that fall in the yellow zone (Figure 7.2). While purse seine fishery has risk index that falls in the desirable green zone. This fishery has a draft management plan that guides its fishing operations. The three other fisheries do not have fisheries management plans. This explains why they have high risk indices.

Table 7.2. Fishery Risk Indices and Ecosystem Risk Index for the Kenyan coral reef ecosystem.

Fishery	Risk Indices	Ecosystem Risk Index
Gillnet fishery	1.28	
Hook and line fishery	1.07	1.10
Traditional trap fishery	1.09	
Purse seine fishery	0.94	

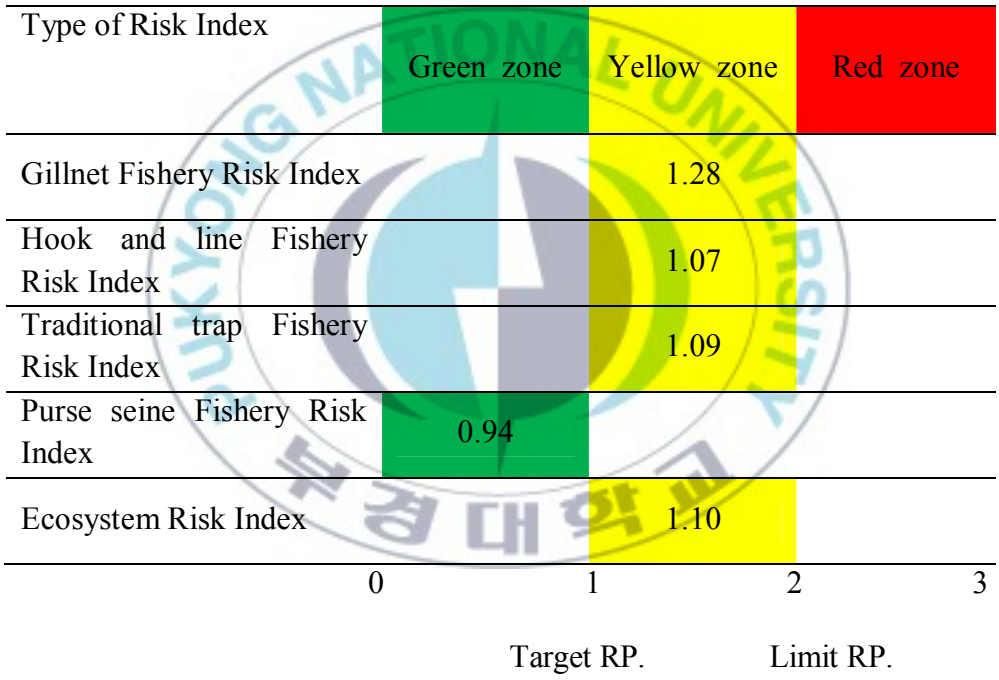

Fig. 7.2. Fishery and ecosystem risk diagram assessed by the Tier 2 approach for the Kenyan coral ecosystem.

Ecosystem risk index of the Kenyan coral reef ecosystem was assessed based on the fishery risk indices from the formula. ERI = $\frac{\sum C_i \quad FRI_i}{\sum \quad C_i}$, C_i is catch since data for biomass was not available.

Four fisheries were assessed in the Kenyan coral reef ecosystem as shown in Table 7.2. The Kenyan coral reef ecosystem has risk index '1.10'. This risk index falls in the yellow zone (Figure 7.2). The Kenyan coral reef ecosystem management system needs to be organized into four management objectives in line with ecosystem approach to fisheries management to reduce fisheries and ecosystem risk indices respectively.

Chapter 8. Suggestions for proper management to reduce risk indices.

The Kenyan coral reef ecosystem has 32 species by four objectives in the yellow zone (Table 6.3). Indicators risk zones are as shown in Table 6.2. Sustainability for the Kenyan coral reef ecosystem has 78.8 % of the indicators in the yellow zone, e.g. Catch per unit effort, fishing effort, rate of mature fish, spawning potential ratio, average length, age (or length) at first capture, mean trophic level of catch, number of spawning population, ratio of coral coverage of fishing area, ratio of seagrass coverage of fishing area and ratio of mangrove coverage of fishing area. Rate of mature fish, fishing effort and mean trophic level of catch are indicators in the red zone with 11.1 %. These are very important indicators for this objective; therefore a proper system of data collection for these indicators is required. A proper management plan in line with ecosystem approach to fisheries management is suggested to reduce high risk indices.

Biodiversity has 31 % of the indicators in the yellow zone, while 4.8 % of the indicators are in the red zone. Indicators in the yellow zone are Shannon-Wiener Diversity Index, number of species in catch, mean trophic level of the community, predator/prey in catch, while indicators in the red zone are bycatch or incidental catch.

Habitat quality has 53.8 % of the indicators in the yellow zone and 15.4 % of the indicators in the red zone. Indicators in the yellow zone are lost fishing gear, runoffs of fresh water, impacted/pristine of corals, impacted/ pristine of mangroves, impacted/ pristine of seagrass and sewage loadings. Some indicators are replicated for different species. Indicators in the red zone are marine protected areas or no take areas and pollution of spawning and nursery areas. Proper system of data collection for these indicators is required. Assessment of risk indices should be done again. Fisheries management plan in line with ecosystem approach to fisheries management for fisheries with these indicators is suggested to reduce risk indices.

Socio-economy has 53.9 % of the indicators in the yellow zone and 1.1 % of the indicators in the red zone. Indicators in the yellow zone are income per person employed, sale/cost, Price of fish, Profit/sale, trophy fish, employment rate, job stability, job satisfaction, commercial/total catch, recreational/total catch, subsistence/total catch and traditional cultural satisfaction. Some indicators are replicated for different species. Indicator in the red zone is trophy fish replicated for different species. A proper system of data collection for these indicators is required. Assessment of risk indices should be done again. Fisheries management plans in line with ecosystem

approach to fisheries management for fisheries with these indicators are suggested to reduce high risk indices.

In conclusion, many indicators require proper scientific data for assessment by the Tier 1 approach. The Tier 2 approach was used to assess risk indices for all the indicators due the quality of the data available. An improvement on the data used for Tier 2 assessment is suggested. This will enable another assessment by the same approach, which will then be compared with Tier 1 approach after better qualitative data collection. Ecosystem approach to fisheries management is currently the core reference point for all fisheries management strategies. Fisheries management plans in line with ecosystem approach to fisheries are suggested to reduce high risk indices. However climate change is expected to influence species diversity, movement, recruitment etc in many ecosystems of the World. Therefore the Integrated Fisheries Risk Analysis Method for Ecosystems (IFRAME) approach that tracks climate change impacts is suggested for the Kenyan coral reef ecosystem for future study since the IFRAME framework is made up of three components: assessment, forecast, and management (Zhang et al. 2011).

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Appendix I: Targets and limit reference points for indicators of sustainability in the Tier 1 EBFA.

Attribute	Indicator	Indicator status		
		Better than target	Between target and limit	Beyond limit
Abundance	Spawning biomass(SB)	$SB_{MSY} \leq SB$	$0.5(SB_{MSY}) \leq SB$ SB_{MSY}	SB $0.5(SB_{MSY})$
	or (CPUE)	$CPUE_{MSY} \leq CPUE$	$0.5(CPUE_{MSY}) \leq CPUE$ $CPUE_{MSY}$	$CPUE$ $0.5(CPUE_{MSY})$
Fishing intensity	Fishing mortality (F) or	$F \leq F_{MSY}$	$F_{MSY} < F \leq 2F_{MSY}$	$2F_{MSY} < F$
	Fishing effort (E)	$E \leq E_{MSY}$	$E_{MSY} < E \leq 2E_{MSY}$	$2E_{MSY} < E$
	Annual catch (C)	$C \leq C_{Limit}$	$C_{Limit} < C < 2C_{Limit}$	$2C_{Limit} < C$
	Rate of mature fish (RMF)	RMF≥60%	40%≤RMF<60%	RMF<40%
Stock structure	Spawning potential ratio (SPR)	SPR≥ 40%	20%≤SPR<40%	SPR<20%
	Average length ($\bar{L}$)	$\bar{L} \geq \bar{L}_{MSY}$	$\bar{L}_{2MSY} \leq \bar{L} < \bar{L}_{MSY}$	$\bar{L} < \bar{L}_{2MSY}$
	Age at (or length) first capture (tc)	$tc \geq tc_{target}$	$tc_{target} > tc \geq tc_{limit}$	$tc < tc_{limit}$
Ecosystem productivity	Mean trophic level of catch (TL_C)	$3.43 \leq TL_C$	$3.26 \leq TL_C < 3.43$	$TL_C < 3.26$
Genetic variability	No. of spawning population (SP)	$SP \geq SP_{target}$	$SP_{limit} \leq SP < SP_{target}$	$SP < SP_{limit}$
Population resiliency in coral reefs, seagrass and mangrove	Changes in ratio of coral coverage of fishing area (CC)	$(CC_{Virgin} - CC_C) < 10\%$	$(CC_{Virgin} - CC_C) < 30\%$	$CC_{Virgin} - CC_C) > 30\%$
(Reproduction habitat)	Changes in ratio of seagrass coverage of fishing area (SC)	$(SC_{Virgin} - SC_C) < 10\%$	$(SC_{Virgin} - SC_C) < 30\%$	$(SC_{Virgin} - SC_C) > 30\%$
	Changes in ratio of mangrove coverage of fishing area (MC)	$(MC_{Virgin} - MC_C) < 10\%$	$(MC_{Virgin} - MC_C) < 30\%$	$(MC_{Virgin} - MC_C) > 30\%$

Appendix II: Targets and limit reference points for indicators of biodiversity in the Tier 1 EBFA.

Attribute	Indicator	Indicator status		
		Better than target	Between target and limit	Beyond limit
Bycatch and discards	Bycatch or Incidental catch (BIC)	$(BIC) \leq (BIC)_{target}$	$(BIC)_{target}<(BIC)\leq(BIC)_{limit}$	$(BIC)>(BIC)_{limit}$
	Discards (DC)	$(DC)\leq (DC)_{target}$	$(DC)_{target}<(DC)\leq(DC)_{limit}$	$(DC)>(DC)_{limit}$
	Shannon-Weiner Diversity Index (DI)	$DI\geq DI_{target}$	$DI_{target}>DI\geq DI_{limit}$	$DI<DI_{limit}$
Taxa richness	Number of species in catch (NS)	$NS\geq NS_{target}$	NS_{target} $NS\leq NS_{limit}$	$NS<NS_{limit}$
Trophic stability	Mean trophic level of the community (TL_{CO})	$TL_{CO}\geq 3.25$	$3.25 >TL_{CO}\geq 2.75$	$TL_{CO}<2.75$
(Community structure)	Predator/prey in catch (P/P)	$(P/P)-(P/P)_{target} \leq 0.1(P/P)_{target}$	$0.1(P/P)_{target} <\|(P/P)-(P/P)_{target}\| \leq 0.2(P/P)_{target}$	$\|(P/P)-(P/P)_{target}\| >0.2(P/P)_{target}$
Integrity of functional groups	Invasive /traditional species in catch (I/T)	$(I/T)\leq 0.1(I/T)_{target}$	$0.1(I/T)_{target}<(I/T)\leq 0.2(I/T)_{target}$	$(I/T)>0.2(I/T)_{target}$

Appendix III: Targets and limit reference points for indicators of habitat quality in the Tier 1 EBFA.

Attributes	Indicator	Indicator status		
		Better than target	Between target and limit	Beyond limit
Habitat protection	Marine protected areas or No take areas (MP)	$(MP) \geq (MP)_{target}$	$(MP)_{target} > (MP) \geq (MP)_{limit}$	$(MP) < (MP)_{limit}$
	Marine national reserves or Low-use areas (MN)	$(MN) \geq (MN)_{target}$	$(MN)_{target} > (MN) \geq (MN)_{limit}$	$(MN) < (MN)_{limit}$
Essential habitats damage	Pollution of spawning and nursery areas (PA)	$PA \leq PA_{target}$	$PA_{target} < PA \leq PA_{limit}$	$PA > PA_{limit}$
	lost fishing gear (FG)	$FG \leq FG_{target}$	$FG_{target} < FG \leq FG_{limit}$	$FG > FG_{limit}$
	Runoffs of freshwater (RF)	$RF \leq RF_{target}$	$RF_{target} < RF \leq RF_{limit}$	$RF > RF_{limit}$
	Impacted/pristine of corals (I/PC)	$I/PC \leq I/PC_{target}$	$I/PC_{target} < I/PC \leq I/PC_{limit}$	$I/PC > I/PC_{limit}$
	Impacted/pristine of mangroves (I/PM)	$I/PM \leq I/PM_{target}$	$I/PM_{target} < I/PM \leq I/PM_{limit}$	$I/PM > I/PM_{limit}$
	Impacted/pristine of seagrass (I/PS)	$I/PS \leq I/PS_{target}$	$I/PS_{target} < I/PS \leq I/PS_{limit}$	$I/PS > I/PS_{limit}$
Discarded wastes	Discarded wastes from fishing vessel (DW)	$DW \leq DW_{target}$	$DW_{target} < DW \leq DW_{limit}$	$DW > DW_{limit}$
	Sewage loading (SL)	$SL \leq SL_{target}$	$SL_{target} < SL \leq SL_{limit}$	$SL > SL_{limit}$

Appendix IV: Target and limit reference points for indicators of socio-economy in the Tier 1 EBFA.

Attribute	Indicator	Indicator status		
		Better than target	Between target and limit	Beyond limit
Economic considerations	Income per person employed (IPPE)	$IPPE \geq IPPE_{target}$	$IPPE_{target} > IPPE \geq IPPE_{limit}$	$IPPE < IPPE_{limit}$
	Sale/cost (RSC)	$(RSC) \geq (RSC)_{target}$	$(RSC)_{target} > (RSC) \geq (RSC)_{limit}$	$(RSC) < (RSC)_{limit}$
	Price of fish (PF)	$(PF) \geq (PF)_{target}$	$(PF)_{target} > (PF) \geq (PF)_{limit}$	$(PF) < (PF)_{limit}$
	Fuel cost (FC)	$FC \leq FC_{target}$	$FC_{target} < FC \leq FC_{limit}$	$FC > FC_{limit}$
	Profit/sale (RPS)	$(RPS) \geq (RPS)_{target}$	$(RPS)_{target} > (RPS) \geq (RPS)_{limit}$	$(RPS) < (RPS)_{limit}$
	Boat ramps (BR)	$BR \geq BR_{target}$	$BR_{target} > BR \geq BR_{limit}$	$BR < BR_{limit}$
	Trophy fish (TF)	$TF \geq TF_{target}$	$TF_{target} > TF \geq TF_{limit}$	$TF < TF_{limit}$
	Permit cost (PC)	$PC \leq PC_{target}$	$PC_{target} < PC \leq PC_{limit}$	$PC > PC_{limit}$
Social considerations	Employment rate (ER)	$ER \geq ER_{target}$	$ER_{target} > ER \geq ER_{limit}$	$ER < ER_{limit}$
	Job stability (JST)	$JST \geq JST_{target}$	$JST_{target} > JST \geq JST_{limit}$	$JST < JST_{limit}$
	Job satisfaction (JSA)	$JSA \geq JSA_{target}$	$JSA_{target} > JSA \geq JSA_{limit}$	$JSA < JSA_{limit}$
User conflicts	Commercial/total catch (C/T)	$(C/T) \geq (C/T)_{target}$	$(C/T)_{target} > (C/T) \geq (C/T)_{limit}$	$(C/T) < (C/T)_{limit}$
	Recreational/total catch (R/T)	$(R/T) \geq (R/T)_{target}$	$(R/T)_{target} > (R/T) \geq (R/T)_{limit}$	$(R/T) < (R/T)_{limit}$
	Subsistence/total catch (S/T)	$(S/T) \geq (S/T)_{target}$	$(S/T)_{target} > (S/T) \geq (S/T)_{limit}$	$(S/T) < (S/T)_{limit}$
Cultural considerations	Traditional cultural satisfaction (CS)	$CS \geq CS_{target}$	$CS_{target} > CS \geq CS_{limit}$	$CS < CS_{limit}$

Appendix V: Target and limit reference points for indicators of sustainability in the Tier 2 EBFA.

Attributes	Indicators	Indicator status						
		Better than target		Between target and limit			Beyond limit	
		0	0.5	1.0	1.5	2.0	2.5	3.0
Abundance	Spawning biomass (SB) or (CPUE)	More than X years of CPUE data are standardized Current CPUE are extremely large compared with average of CPUE during X years	More than X years of CPUE data are standardized Current CPUE are large compared with average of CPUE during X years	More than X years of CPUE data are available but not standardized Current CPUE are moderately large compared with average of CPUE during X years or Less than X years of CPUE data are Current CPUE are moderately large compared with average of CPUE during X years	Less than X years of CPUE data are standardized CPUE is Unchanged or Less than X years of CPUE data are available but not Standardized Current CPUE is similar to average of CPUE during X years	Less than X years of CPUE data are available but not standardized Current CPUE is moderately small compared with average of CPUE during X years	CPUE data are not available, catch trend is unchanged or, CPUE data are available, current CPUE are small compared with average of CPUE during X years	CPUE data are not available, catch trend is declining or, CPUE data are available, current CPUE are extremely small compared with average of CPUE during X years

Fishing intensity	Fishing mortality(F) or Fishing effort (E)	Effort is extremely small compared with average of effort during X years Fishery management and active self-regulation exist	Effort is small compared with average of effort during X years Fishery management or self-regulation exist	Effort is moderately small compared with average of effort during X years Fishery management or self-regulation exist partly	Effort is similar to average of effort during X years	Effort is moderately large compared with average of effort during X years	Number of license or fishing gear is unchanged or Effort is in an increasing state or IUU fishery exist partly	Number of license or fishing gear is excessive or Effort rapidly increasing or IUU fishery exist largely
Stock structure	Rate of mature fish (RMF)	Fishing never occurs during the spawning season or Prohibition season (prohibition fishing ground) is set up and conduct to conserve mature fish	No more than a minor amount of the catch is taken during the spawning season	No more than a moderate amount of the catch is allowed to be harvested during spawning season	No more than a moderate to considerable amount of fish is allowed to be taken during the spawning season	A significant amount of catch is allowed to be taken during the spawning season	A significant amount of catch is taken as most of the fishery takes place during the spawning season	Fishing activities are free to operate whenever during the spawning season
	Spawning potential ratio (SPR)	Ratio of fished spawning population to unfished is extremely small	Ratio of fished spawning population to unfished is small	Ratio of fished spawning population to unfished is moderately small	Ratio of fished spawning population to unfished is average	Ratio of fished spawning population to unfished is moderately large	Ratio of fished spawning population to unfished is large	Ratio of fished spawning population to unfished is extremely large

	Average length ($\bar{L}$)	Average length of catch is extremely large compared with mature length	Average length of catch is large compared with mature length	Average length of catch is moderately large compared with mature length	Average length of catch is similar to mature length	Average length of catch is moderately small compared with mature length	Average length of catch is small compared with mature length	Average length of catch is extremely small compared with mature length
	Age (or length) at first capture (tc)	Length at first capture is extremely large compared with mature length	Length at first capture is large compared with mature length	Length at first capture is moderately large compared with mature length	Length at first capture is similar to mature length	Length at first capture is moderately small compared with mature length	Length at first capture is small compared with mature length	Length at first capture is extremely small compared with mature length
	Mean trophic level of catch (TL_C)	Ratio of herbivorous to carnivorous in catch is extremely small	Ratio of herbivorous to carnivorous in catch is small	Ratio of herbivorous to carnivorous in catch is moderately small	Ratio of herbivorous to carnivorous in catch is average	Ratio of herbivorous to carnivorous in catch is moderately large	Ratio of herbivorous to carnivorous in catch is large	Ratio of herbivorous to carnivorous in catch is extremely large
Genetic variability	Number of spawning population (SP)	There are none spawning population in catch	A few spawning population exist in catch	Some spawning population exist in catch	Number of spawning population in catch is average	Number of Spawning population in catch is major	Most of the catch consist of the spawning population	All the catch consist of the spawning population
Population Resiliency (Reproduction habitat)	Changes in ratio of coral coverage of fishing area (CC)	Coral coverage of fishing area is extremely large	Coral coverage of fishing area is large	Coral coverage of fishing area is moderately large	Coral coverage of fishing area is average	Coral coverage of fishing area is moderately small	Coral coverage of fishing area is small	Coral coverage of fishing area is extremely small
	Changes in ratio of seagrass coverage of fishing area (SC)	Seagrass coverage of fishing area is extremely large	Seagrass coverage of fishing area is large	Seagrass coverage of fishing area is moderately large	Seagrass coverage of fishing area is average	Seagrass coverage of fishing area is moderately small	Seagrass coverage of fishing area is small	Seagrass coverage of fishing area is extremely small
	Changes in ratio of mangrove coverage of fishing area (MC)	Mangrove coverage of fishing area is extremely large	Mangrove coverage of fishing area is large	Mangrove coverage of fishing area is moderately large	Mangrove coverage of fishing area is average	Mangrove coverage of fishing area moderately small	Mangrove coverage of fishing area is small	Mangrove coverage of fishing area is extremely small

Appendix VI: Target and limit reference points for indicators of biodiversity in the Tier 2 EBFA.

Attributes	Indicators	Indicator status						
		Better than target			Between target and limit		Beyond limit	
		0	0.5	1.0	1.5	2.0	2.5	3.0
Bycatch and discards	Bycatch or Incidental catch (BIC)	Catch of non-target species is extremely small	Catch of non-target species is small	Catch of non-target species is moderately small	Catch of non-target species is average	Catch of non-target species is moderately large	Catch of non-target species is large	Catch of non-target species is extremely large
	Discards (DC)	Amount of discarded fish is extremely small	Amount of discarded fish is small	Amount of discarded fish is moderately small	Amount of discarded fish is average	Amount of discarded fish is moderately large	Amount of discarded fish is large	Amount of discarded fish is extremely large
Taxa richness	Diversity index (DI)	Dominant species is unchanged	Dominant species is unchanged	Dominant species is unchanged	Dormant species is partly changed	Dominant species is some changed	Dominant species is considerably changed	Dominant species is most changed
	Number of species in catch (NS)	Number of species is unchanged	Number of species is unchanged	Number of species is unchanged	Number of species is part decreased	Number of species is some decreased	Number of species is considerably decreased	Number of species is most decreased
Trophic stability	Mean trophic level of community (TL_{CO})	Mean trophic level of community is extremely small	Mean trophic level of community is small	Mean trophic level of community is moderately small	Mean trophic level of community is average	Mean trophic level of community is moderately large	Mean trophic level of community is large	Mean trophic level of community is extremely large
	Predator/prey in catch	Changes in predator/prey in catch is optimal.	Changes in predator/prey in catch is negligible.	Changes in predator/prey in catch is minor.	Changes in predator/prey in catch is moderate.	Changes in predator/prey in catch is major.	Changes in predator/prey in catch is severe.	Changes in predator/prey in catch is very catastrophic.
	Invasive/ traditional species in catch	Changes in invasive/ traditional species in catch is optimal	Changes in invasive/ traditional species in catch is negligible	Changes in invasive/ traditional species in catch is minor	Changes in invasive/ traditional species in catch is moderate	Changes in invasive/traditional species in catch is major	Changes in invasive/ traditional species in catch is severe	Changes in invasive/ traditional species in catch is catastrophic

Appendix VII: Target and limit reference points for indicators of habitat quality in the Tier 2 EBFA.

Attributes	Indicators	Indicator status						
		Better than target			Between target and limit		Beyond limit	
		0	0.5	1.0	1.5	2.0	2.5	3.0
Habitat Protection	Marine protected areas or No take areas (MP)	Marine protected area total area is extremely large compared with total coral reef area	Marine protected area total area is large compared with total coral reef area	Marine protected area total area is moderately large compared with total coral reef area	Marine protected area total area is average compared with total coral reef area	Marine protected area total area is moderately small compared with total coral reef area	Marine protected area total area is small compared with total coral reef area	Marine protected area total area is extremely small compared with total coral reef area
	Marine national reserves or Low use areas (MN)	Marine national reserve total area is extremely large compared with total coral reef area	Marine national reserve total area is large compared with total coral reef area	Marine National reserve total area is moderately large compared with total coral reef area	Marine national reserve total area is average compared with total coral reef area	Marine national reserve total area is moderately small compared with total coral reef area	Marine national reserve total area is small compared with total coral reef area	Marine national reserve total area is extremely small compared with total coral reef area
	Pollution of spawning and nursery areas (PA)	There is information on the magnitude of pollution by the target fishery on the spawning and nursery areas	There is information on the magnitude of pollution by the target fishery on the spawning and nursery areas	There is information on the magnitude of pollution by the target fishery on the spawning and nursery areas	There is information on the magnitude of pollution by the target fishery on the spawning and nursery areas	There is information on the magnitude of pollution by the target fishery on the spawning and nursery areas	There is no information on the magnitude of pollution by the target fishery on the spawning and nursery areas	There is no information on the magnitude of pollution by the target fishery on the spawning and nursery areas

	no pollution by the target fishery on the spawning and nursery areas no oil spillage accident	a few pollution by target fishery on the spawning andn ursery areas	some pollution by the target fishery on the spawning and nursery areas	considerable pollution by the target fishery on the spawning and nursery areas	much pollution by the target fishery on the spawning and nursery areas	existence of oil spillage accident within recent 3-5 years	existence of oil spillage accident within recent 3years
Lost fishing gear (FG)	Possibility for potential loss of fishing gear is high degree of uncertain	Possibility for potential loss of fishing gear is highly unlikely	Possibility for potential loss of fishing gear is unlikely	Possibility for potential loss of fishing gear is ambiguous	Possibility for potential loss of fishing gear is likely	Possibility for potential loss of fishing gear is highly likely	Possibility for potential loss of fishing gear is high degree of certainty
Runoffs of freshwater (RF)	Amount of runoffs for recent X years is extremely small	Amount of runoffs for recent X years is small	Amount of runoffs for recent X years is moderately small	Amount of runoffs for recent X years is average	Amount of runoffs for recent X years is moderately large	Amount of runoffs for recent X years is large	Amount of runoffs for recent X years is extremely large
Impacted/pristine of corals (I/PC)	Impacted /pristine of corals coverage for recent X years is extremely small	Impacted /pristine of corals coverage for recent X years is small	Impacted /pristine of corals coverage for recent X years is moderately small	Impacted /pristine of corals coverage for recent X years is average	Impacted /pristine of corals coverage for recent X years is moderately large	Impacted/pristine of corals coverage for recent X years is large	Impacted/pristine of corals coverage for recent X years is extremely large

	Impacted/pristine of mangroves (I/PM)	Impacted/pristine of mangroves coverage for recent X years is extremely small	Impacted /pristine of mangroves coverage for recent X years is small	Impacted /pristine of mangroves coverage for recent X years is moderately small	Impacted/pristine of mangroves coverage for recent X years is average	Impacted/ pristine of mangroves coverage for recent X years is moderately large	Impacted /pristine of mangroves coverage for recent X years is large	Impacted/pristine of mangroves coverage for recent X years is extremely large
	Impacted/pristine of seagrass (I/PS)	Impacted/pristine of seagrass coverage for recent X years is extremely small	Impacted /pristine of seagrass coverage for recent X years is small	Impacted/pristine of seagrass coverage for recent X years is moderately small	Impacted/pristine of seagrass coverage for recent X years is average	Impacted/pristine seagrass coverage for recent X years is moderately large	Impacted /pristine of seagrass coverage for recent X years is large	Impacted/pristine of seagrass coverage for recent X years is extremely large
Discarded wastes	Discarded wastes from fishing vessels (DW)	Quantity of discarded wastes is extremely small	Quantity of discarded wastes is small	Quantity of discarded wastes is moderately small	Quantity of discarded wastes is average	Quantity of discarded wastes is moderately large	Quantity of discarded wastes is large	Quantity of discarded wastes is extremely large or Fatal fishing wastes are being discarded
	Sewage loadings (SL)	Quantity of Sewage loadings is extremely small	Quantity of sewage loadings is small	Quantity of sewage loadings is moderately small	Quantity of sewage loadings is average	Quantity of sewage loadings is moderately large	Quantity of sewage loadings is large	Quantity of sewage loadings is extremely large

Appendix VIII: Target and limit reference points for indicators of socio-economy in the Tier 2 EBFA.

Attribute	Indicator	Indicator status						
		Better than target		Between target and limit			Beyond limit	
		0	0.5	1.0	1.5	2.0	2.5	3.0
Economic considerations	Income per person employed (IPPE)	Income for recent X years is extremely larger than the minimum living cost	Income for recent X years is larger than the minimum living cost	Income for recent X years is moderately larger than the minimum living cost	Income for recent X years is similar to the minimum living cost	Income for recent X years is moderately smaller than minimum living cost	Income for recent X years is smaller than the minimum living cost	Income for recent X years is extremely smaller than the minimum living cost
		Income is Increasing or stable	Income is increasing or stable	Income is increasing or stable	Income is stable	Income is stable	Income is stable or decreasing	Income is decreasing
	Sale/cost (RCS)	Sale /cost for target fishery is extremely high	Sale/cost for target fishery is high	Sale/cost for target fishery is moderately high	Sale/cost for target fishery is average	Sale/cost for target fishery is moderately low	Sale/cost for target fishery is low	Sale/cost for target fishery is extremely low
	Price of fish (PF)	Price of fish for target species is extremely high	Price of fish for target species is high	Price of fish for target species is moderately high	Price of fish for target species is average	Price of fish for target species is moderately low	Price of fish for target species is low	Price of fish for target species is extremely low
	Fuel cost (FC)	Fuel cost for target fishery is extremely low	Fuel cost for target fishery is low	Fuel cost for target fishery is moderate low	Fuel cost for target fishery is average	Fuel cost for target fishery is moderately high	Fuel cost for target fishery is high	Fuel cost for target fishery is extremely high

	Profit/sale (RPS)	Profit/sale by the fishery is extremely high	Profit /sale by the fishery is high	Profit/sale by the fishery is moderately high	Profit/sale by the fishery is average	Profit/sale by the fishery is moderately low	Profit/sale by the fishery is low	Profit/sale by the fishery is extremely low
	Boat ramps (BR)	Boat ramps use rate is extremely low	Boat ramps use rate is low	Boat ramps use rate is moderately low	Boat ramps use rate is average	Boat ramps use rate is moderately high	Boat ramps use rate is high	Boat ramps use rate is extremely high
	Trophy fish (TF)	Trophy fish catch rate is extremely high	Trophy fish catch rate is high	Trophy fish catch rate is moderately high	Trophy fish catch rate is average	Trophy fish catch rate is moderately low	Trophy fish catch rate is low	Trophy fish catch rate is extremely low
	Permit cost (PC)	Permit cost is extremely low	Permit cost is low	Permit cost is moderately low	Permit cost is average	Permit cost is moderately high	Permit cost is high	Permit cost is extremely high
Social considerations	Employment rate (ER)	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is extremely large	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is large	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is moderately large	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is average	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is moderately small	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is small	Index of fishery employment (number of fishermen X actual fishing days) for recent X years is extremely small
	Job stability (JST)	Job stability of the fishery has high degree of certainty	Job stability of the fishery is highly likely	Job stability of the fishery is likely	Job stability of the fishery is ambiguous	Job stability of the fishery is unlikely	Job stability of the fishery is highly unlikely	Job stability of the fishery has high degree of uncertainty
	Job satisfaction (JSA)	Job satisfaction of the fishery is optimal	Job satisfaction of the fishery is negligible	Job satisfaction of the fishery is minor	Job satisfaction of the fishery is moderate	Job satisfaction of the fishery is major	Job satisfaction of the fishery is severe	Job satisfaction of the fishery is catastrophic

	Commercial/ total catch (C/T)	Changes in commercial/ total catch for recent X years is extremely small	Changes in commercial/ total catch for recent X years is small	Changes in commercial/ total catch for recent X years is moderately small	Changes in commercial/ total catch for recent X years is average	Changes in commercial/ total catch for recent X years is moderately large	Changes in commercial/ total catch for recent X years is large	Changes in commercial/ total catch for recent X years is extremely large
User conflicts	Recreational/ total catch (R/T)	Changes in recreational/ total catch for recent X years is extremely small	Changes in recreational/ total catch for recent X years is small	Changes in recreational/ total catch for recent X years is moderately small	Changes in recreational/ total catch for recent X years is average	Changes in recreational/ total catch for recent X years is moderately large	Changes in recreational/ total catch for recent X years is large	Changes in recreational/ total catch for recent X years is extremely large
	Subsistence/ total catch (S/T)	Changes in household /total catch for recent X years is extremely small	Changes in household /total catch for recent X years is small	Changes in household /total catch for recent X years is moderately small	Changes in household /total catch recent X years is average	Changes in household /total catch for recent X years is moderately large	Changes in household /total catch for recent X years is large	Changes in household /total catch for recent X years is extremely large
Cultural considerations	Traditional cultural satisfaction (CS)	Traditional cultural satisfaction of the fishery is optimal	Traditional cultural satisfaction of the fishery is negligible	Traditional cultural satisfaction of the fishery is minor	Traditional cultural satisfaction of the fishery is moderate	Traditional cultural satisfaction of the fishery is major	Traditional cultural satisfaction of the fishery is severe	Traditional cultural satisfaction of the fishery is catastrophic

Appendix IX: Criteria of risk states for semi quantitative assessment of the Tier 2 EBFA.

Magnitude	Abundance	Condition	Likelihood	Risk score	Percentage (%)
Extremely small	Never or None	Optimal, Best	High degree of uncertainty	0	< 5%
Small	Part or a few	Negligible	Highly unlikely	0.5	5 -20%
Moderately small	Some	Minor	Unlikely	1.0	20 -40%
Average	Considerable or Average	Moderate	Ambiguous	1.5	40 -60%
Moderately large	Many or Major	Major	Likely	2.0	60 -80%
Large	Most	Severe	Highly likely	2.5	80 -95%
Extremely large	All	Catastrophic, Worst	High degree of certainty, Evident	3.0	>95%