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Review of Ecosystem-Bycatch Issues for the Western and Central Pacific Region

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Executive Summary

This report provides a review of relevant information on ecosystem and bycatch issues for use by the Commission, taking into account information available from existing bodies. This report presents a review of current thinking on the scientific basis for taking an ecosystem approach to fishery management, previously published ecosystem principles and objectives, and ecosystem issues of particular relevance to pelagic fisheries in the WCPO.

Background

"Ecosystem Management" found formal acceptance at the Earth Summit in Rio de Janeiro in 1992 and was described as: *"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way."* Application of the ecosystem approach will help to reach a balance of the three main objectives of rational resource management: conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilisation of genetic resources. Articles 5 and 6 of the Convention make it clear that ecosystem effects should play a large role in shaping management measures for fisheries in the WCPO.

National strategies

Several Pacific Island countries now have formal fisheries management plans that may include some policies regarding bycatch and ecosystem issues in general. Few, if any, have reached the stage of actually implementing ecosystem provisions in fisheries management. However, on behalf of its member countries, SPC is involved in the types of research that are required to support ecosystem approaches to management.

In addition to the status of ecosystem based fishery management in the island nations, as an example, the report describes national strategies for three non-island nations with interests in the WCPO: Australia, the USA and the UK.

Data and research requirements

Taking into account ecosystem considerations in the management of fisheries requires substantial amounts of data on target species, interactions between target species and other species, food webs, and the direct effects of fishing on non-target species and their habitat. To meet the objectives of the WCPFO Convention will require substantial input into modelling and monitoring of target fisheries and the environment in which they exist.

The most important element of the monitoring program is to determine the measures of the environment that will lead to the most appropriate management action. That is, one must identify the variables of interest, the magnitude of change or difference in those variables that would warrant action and the temporal scale on which management decisions need to be made. For example, managers would ideally prefer to receive feedback on the scale of one to two years concerning how to manage fisheries when faced with a possible impact on a threatened or endangered species, rather than obtaining feedback over a longer period, say 10 years. Information on population abundance is unlikely to provide such information in that time frame, even in the absence of fishing.

Section 2.4.2 of the report reviews existing work being undertaken under two important research programs in the WCPO that provide results that support the development of an ecosystem approach to managing tuna fisheries in this region: The Oceanic Fisheries Program of SPC and the Pelagic Fisheries Research Program of the University of Hawaii.

Ecosystem effects

A conceptual framework for considering the ecosystem effects of fishing must focus on three types of effects:

- incidental mortality of non-target species in fisheries operations;
- indirect effects on food webs; and
- direct effects on habitat.

The western and central Pacific Ocean currently supports the largest industrial tuna fishery in the world, with an estimated annual catches averaging about 1.5 million metric tons over the past decade. All of these fisheries have some level of catch of non-target species (bycatch). A portion of this bycatch is discarded because it has little or no economic value. A portion of the target catch is also often discarded for economic reasons, or because it is damaged, physically too small for efficient processing, or lost because of gear failures during fishing operations. Marine mammals, seabirds, and sea turtles make up a component of the bycatch that varies with gear and area. Section 3.2 of the report provides a detailed review of existing information on bycatch by fishing gears and by target species, including some information on approaches to reducing bycatch.

In considering food web effects, the report explains that adult tunas and billfish are at the apex of pelagic food webs in the WCPO. Much of the concern regarding the effects of fishing on marine food webs stems from targeting on species at lower trophic levels, and particularly prey or forage species on which higher level predators rely, rather than species in the upper levels. however, there is growing body of evidence that changes at the tops of food webs are expressed at all trophic levels in a wide variety of aquatic ecosystems. More work needs to be done to better understand how the effects of removal of higher predators propagate through the food web, but it is clear that the status of these apex predators and their ecological significance can only be known through monitoring of fisheries and diet composition.

Habitat diversity is the most frequently used quantitative measure of biodiversity because habitat can be defined relatively clearly in terms of both physical conditions and biotic components. Loss and/or degradation of habitat is currently recognised as the most critical threat to marine biodiversity. The corollary of this is that prevention of such loss or degradation is considered to be the most effective way of conserving biodiversity.

Enhanced and directed monitoring is an essential element of an ecosystem approach that seeks to take into consideration unintentional, secondary and/or indirect effects of fishing on target species with particular fishing gears. Increased use of observers is the best means currently available of obtaining independent information on catch and bycatch statistics at the species level. Modelling is also required to develop a better understanding of ecological relationships and ecosystem effects, and to explore in advance the effects of different management alternatives and their monitoring requirements.

There is a need to develop target and thresholds measured in ecosystem properties that can be used to guide managers in a similar way to single-species definitions of overfishing.

1 Introduction

During the second session of the Preparatory Conference (PrepCon2), WGII reviewed and gave preliminary consideration to the Commission's needs with respect to:

1. data requirements, including current gaps in data coverage and standards for data collection and management;
2. science, and in particular stock assessment and advice on stock status in the short term and ongoing;
3. research priorities and research planning and coordination;
4. review of assessments, analyses and other scientific work.

WGII established an ad-hoc task group to consider the future information needs to support discussions and progress on matters related to the scientific activities of the Commission. Drawing upon the material from the ad-hoc task group the working group agreed that prior to the next meeting of the working group there should be a review of relevant information on ecosystem and bycatch issues for use by the Commission taking into account information available from existing bodies, including the SCTB Billfish and Bycatch Research Group, and paying particular attention to incidental catches of sensitive species.

In this regard, Working Group II has noted that research on the pelagic ecosystem and on ecosystem-based fishery management is an on-going research priority throughout the world. The Group also noted that these research results will eventually become important in the work of the Commission, but is probably not a priority for the interim period. Nevertheless, it is important to build an information base from which to develop management strategies that will be sensitive both to the effects of fishing on the environment and the effects of the environment on fish productivity.

In this report, we present a review of current thinking on the scientific basis for taking an ecosystem approach to fishery management, and previously published ecosystem principles and objectives, including a selection of national and international policy documents. The remainder of the document considers ecosystem issues of particular relevance to pelagic fisheries in the WCPO, including a review of information available from the SCTB Billfish and Bycatch Research Group on bycatch by gear and species.

Conventional stock assessment tends to focus only on the effects of fishing on target species and does not take explicit account of ecological and ecosystem considerations. By contrast, the ecosystem-based approach recognizes that stocks sit within a food web (almost all species are both predators and prey), that non-human predators of stocks are competitors with fishing, and that the abiotic environment is part of the milieu in which organisms live and fishing occurs.

2 Ecosystem-based management of fisheries

2.1 What is ecosystem-based management?

The phrase 'Ecosystem Approach' was first coined in the early 80s, but found formal acceptance at the Earth Summit in Rio de Janeiro in 1992 where it became an underpinning concept of the Convention on Biological Diversity, and was later described as:

'a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way.'

Application of the ecosystem approach will help to reach a balance of the three main objectives of rational resource management: conservation; sustainable use; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. It is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems.[1]

Similarly, Margalef (in Smith 1994, pg. 8) states "Ecosystems result from the integration of populations of different species in a common environment. They rarely remain steady for long, and fluctuations lie in the very essence of the ecosystems and of every one of the…populations [that comprise the system]".

Modification of the marine ecosystem is an inevitable consequence of the scale of human activity in areas such as fishing and coastal development. Marine fisheries are one of the remaining examples of large-scale human activity involving the direct exploitation of wild animal populations. Fisheries are dependent on the productivity of the ecosystem, and fisheries have an effect on, and are affected by, the supporting ecosystem of the target species. It, therefore, follows that prudent and responsible fisheries management should take account of the profound interactions between fisheries and their supporting ecosystem.

Without human intervention, populations of species exist in the ecosystem in their "natural" state and the "needs" of these populations are met to a greater or lesser extent. Human intervention, such as fishing, modifies the properties of the ecosystem in a variety of ways, such that it may no longer meet the needs of the species that exist within it in the same way as it did without intervention.

It is possible and valuable, however, to conduct fishery management while recognizing ecosystem effects and taking ecological considerations into account. The concept of "rational use" of living marine resources is now widely accepted and enshrined in international agreements, such as the CCAMLR[2] Convention, which aims to take an "ecosystem approach" while allowing fisheries to proceed on a rational basis. Conservation is therefore concerned with how we sustain renewable resources in ecosystems so that future options are maintained[3]. The

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[1] Web site of the Convention on Biological Diversity (http://www.biodiv.org/programmes/cross-cutting/ecosystem/).

[2] Commission for the Conservation of Antarctic Marine Living Resources

[3] The FAO Fisheries Atlas, in its section on 'Basic Principles of Ecosystem Management', states: 'The overarching principles of ecosystem-based management of fisheries…aim to ensure that, despite variability, uncertainty and likely natural changes in the ecosystem, the capacity of the aquatic ecosystems to produce food, revenues, employment and, more generally, other essential services and livelihood, is maintained indefinitely for the benefit of the present and future generations…to cater both for human as well as ecosystem well-being. This implies conservation of ecosystem structures, processes and interactions

question that science needs to answer is, does fishery management limit modification of ecosystem properties, such that the ecosystem continues to support the needs of the species it contains in the way that it did prior to modification?

This immediately and clearly demonstrates the complexity of fishery management taking account of ecological and ecosystem considerations. In order to show how human intervention has modified the ecosystem, and the extent to which this modification compromises ecosystem function, it is necessary to have some way of measuring and evaluating ecosystem function under various states of nature, both with and without human intervention.

Thus, it becomes clear that what is being managed in natural resource contexts is human intervention in ecosystems, not the species or the ecosystems themselves. This has consequences for the terminology that is generally used to describe the process of managing fisheries while being considerate of the needs non-target species in the ecosystem. Frequently the term "ecosystem management" is used, but since we cannot profess to manage ecosystem processes such as regime shifts, changes in food webs, or climate change, this is patently inappropriate. We prefer more accurate terms such as "ecosystem-based approach to management", "fishery management with an ecosystem perspective" or "fishery management taking account of ecological and ecosystem considerations".

The Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem[4] sought to establish a means by which ecosystem considerations could be included in capture fisheries management, and to identify future challenges and relevant strategies. Michael Sinclair, co-chair of the scientific symposium summarized discussion from the scientific symposium (FAO 2001). He noted that although no formal definition of ecosystem-based fishery management had been agreed to, there was consensus that an ecosystem-based fishery management approach contained the following features:

- integrated management of multiple fisheries and other ocean uses within a geographic context;
- incorporation of a broader set of objectives than currently exists; and
- direct management of human activities, rather than the ecosystem itself.

Although it was agreed that additional knowledge on marine ecosystems was needed, the introduction and development of ecosystem-based fishery management should start now and that it could be initiated in both developed and developing countries. He concluded that ecosystem-based fishery management would probably be implemented through an evolutionary, not revolutionary, process and that the precautionary principle was an integral component in the ecosystem-based fishery management approach.

The Reykjavik Declaration stated (FAO 2001), *inter alia*, that while immediate action on particularly urgent problems using a precautionary approach is needed, scientific knowledge needs to be advanced in several areas, including: the sustainable management strategies that incorporate ecosystem considerations; characteristics of relevant marine ecosystems, diet composition and food webs, species interactions and predator-prey relationships, and the role of habitat and factors affecting ecosystem stability and resilience; systematic monitoring of natural variability, and its effect on ecosystem productivity; monitoring of by-catch and discards in all fisheries; fishing gear and practices; and the adverse human impacts of non-fisheries activities.

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through sustainable use. This implies consideration of a range of frequently conflicting objectives and the needed consensus may not be achievable without equitable distribution of benefits.'

[4] October 2001 in Reykjavik, Iceland, http://www.refisheries2001.org/.

2.2 Building a management framework for ecosystem-based management of fisheries

2.2.1 Building on conventional assessment techniques

Conventional stock assessment tends to focus only on the effects of fishing on target species and does not take explicit account of ecological and ecosystem considerations. This conventional view recognizes the biophysical world in which fish stocks exists, the socio-economic world of the fishing community that takes the stock, and the management world in which catch limits and other controls on fishing activity are determined and implemented (Figure 1). However, it does not recognise the potential effects of removals on non-target species, either directly through mortality, or indirectly through food-web relationships. Nor does it consider the effects of fishing gear on habitat, and the knock-on effects of habitat condition on fish productivity. Finally it does not account specifically for environmental fluctuations that may affect stock productivity in a variety of different ways.

Use of conventional single-species management makes the assumptions that:

- stocks can be viewed out of the context of their role in the ecosystem,
- density dependence is the main regulating factor in population dynamics, and
- if one simply knows enough about the vital information of the stock, then it is possible to fully control the trajectory of the stock.

These assumptions are relied upon whether one uses surplus production models, dynamic pool models, stock-recruitment models, Virtual Population Analysis, or other more sophisticated tools.

By contrast, the ecosystem-based approach recognizes that stocks sit within a food web (almost all species are both predators and prey; Pauly and Christensen 1995, Pauly *et al.* 1998), that non-human predators of stocks are competitors with fishing (e.g. Punt 1997, Fryer 1998), and that the abiotic environment is part of the milieu in which organisms live and fishing occurs. Belsky (1993, pg. 229) writes, "The ecosystem model [in the sense of a conceptual framework] is nothing more than a shorthand for holistic or comprehensive ocean management. The mandate for use of this model seeks to force government leaders to apply scientific principles to domestic and international law and policymaking".

Grumbine (1994) provides the following attributes of ecosystem-based resource management:

1. *Interactions between ecological levels*: Management ensures that connections between and across all levels (species, populations, habitats, regions) are taken into account in resolving issues - focus on any one level is inadequate;
2. *Ecosystem boundaries*: Management acts within ecological boundaries and across administrative, political and jurisdictional boundaries;
3. *Maintenance of ecosystem integrity*: Management's focus includes the maintenance of ecological integrity. It has the stewardship of total national biological diversity (genes, species, communities, habitats) and the ecological processes that maintain that diversity, rather than a narrower focus on the benefits to particular sectors or areas;
4. *Data collection*: Management collects information beyond that required to manage individual sectors. It includes an inventory of biodiversity assets, baseline assessments of ecosystem functions, measurements of the interactions of sectors and improved management and use of existing data.
5. *Monitoring of management*: Management uses measurable performance indicators to assess the success or failure of its actions. Monitoring provides feedback that is critical to evaluating and refining management approaches;

6. *Adaptive and precautionary management*: Management acknowledges that, as scientific and other information is necessarily incomplete, actions with poorly understood or difficult to reverse consequences are to be avoided. Adaptive management regards management as a learning process, where incorporating the experience from previous actions and improved knowledge of the system enables managers to adapt to changing levels of uncertainty and to improve progressively.
7. *Inter-agency cooperation*: Management improves inter-agency cooperation because ecological boundaries cross-traditional agency and administrative divides and Commonwealth, State and local government jurisdictions. Managers work together across such boundaries to integrate conflicting legal mandates, management practices and priorities.
8. *Organisational change*: Management recognises that the orientation, structure and modus operandi of agencies that manage ocean uses will be different from sector-based agencies. The differences may be relatively simple arrangements for inter-agency coordination, or more fundamental shifts in lines of accountability, responsibility, organisational orientation, decision-making processes, priorities and operations.
9. *Management of human activities*: Management recognises that human activities are fundamental influences on many marine ecological patterns and processes and are in turn affected by them. Although human activities are the focus of most management actions, they are recognised as being embedded in marine ecosystem functioning.
10. *Values*: Management recognises, accepts and incorporates biodiversity values into all resource allocation processes that could affect the ocean ecosystems, even when scientific and technical knowledge may be insufficient for a full definition of values. Management recognises, however, that human values will play a dominant role in decisions on ocean uses.

A management plan that recognizes ecological and ecosystem effects must be broader and deeper than the conventional world-view, as it attempts to deal with three interlocking goals (Larkin 1996):

1. a sustainable yield of products for human consumption and animal foods;
2. maintenance of biodiversity; and
3. protection from the effects of pollution and habitat degradation.

Furthermore, this approach tends to embrace a greater range of variation and uncertainty. Bakun (1996) and Spencer and Collie (1997) give examples of dome-shaped time series of stocks that include waxing, waning, and crashing stocks. For example, stocks that rose from the mid 1970s to mid 1980s including sardines (Japan, Peru-Chile, California), anchovy (Benguela), and north Pacific groundfish. Stocks in the opposite phase were anchovies (Japan, Peru-Chile, California) and north Pacific albacore. The Gulf of Guinea sardine population expanded in the mid-1970s and has not yet peaked, while the Brazilian sardine and northern cod stocks declined following the mid-1980s.

Most fisheries stock assessment models recognize effects other than fisheries on the population. For example, in standard age structured models, the dynamics that relate the numbers of individuals from one year to the next assume that when fish disappear, a fraction $F/(F+M)$, of the fish are taken by the fishery, and the remaining fraction $M/(F+M)$ of the fish that disappear go to “natural” predators. The choice of $F/(F+M)$ makes an assumption that the effect of the fishery is the same as the effect of all other predators combined; whether this is true is generally unknown.

Depending on the relative levels of F and M and how the model uses them, this approach may contain an implicit allowance for the predators of the target population, even though there is no explicit consideration of predator needs when catch limits are determined (Figure 2). However, taking ecological and ecosystem considerations into account in fishery management calls for an explicit view of ecosystem effects. The first step beyond the implicit approach is illustrated in Figure 3. Here the status of predators of the target species, which may compete for resources with the fishery, is assessed using quantitative methods. The results of this analysis are fed into the management procedure, but are not integrated with the analysis that focuses on the target species. Similarly, there may be some environmental information that influences decisions at the management level, but again this is outside of the analytical process. The essential characteristic of this stage is that there is no link made between the fishery and its effects on ecosystem properties other than the direct effects on the target population.

The first stage at which the assessment and management process really begins to embrace explicitly the ecosystem approach is illustrated in Figure 4. Here, information from the environment, including non-target species is fed directly into the assessment process, and influences the scientific advice that is provided to managers. The fundamental difference between this stage and that described in Figure 3 is the difference between the population ecology and community ecology views of management. That is, putting the predators in the lowest box in Figure 4 is a more explicit treatment of the community issues.

In the final stage (Figure 5), the environment, target stock, and its predators and prey are integrated in the assessment before the management procedure is used to determine catch limits and other management measures. At the same time, the more complex and less tractable ecosystem problems are included (see Section 2.2.3 for an explanation of more and less tractable ecosystem problems).

It is common to use a number of discreet stages such as these to describe the range of options available to managers between an essentially single species approach and an explicit ecosystem approach. However, in reality, there is a continuum of modifications and adjustments to current thinking and practice that can move the management process towards the more desirable goal of fishery management taking account of ecological and ecosystem considerations (Figure 5). These modifications and adjustments may require substantial time and resources to achieve, not least because our current state of knowledge, and particularly our ability to predict future states of nature and the effects of fishing on them is limited.

All fishery management regimes are at some point along this continuum and are addressing their management goals with varying degrees of success. It is important, however, not to consider current approaches as necessarily wrong simply because they do not take ecosystem considerations explicitly into account. There may be perfectly good reasons why this is either not possible or not necessary, in which case an implicit approach, based on incorporation of uncertainty into the process, is likely to be the best way forward.

2.2.2 Selected published guidance on the ecosystem approach

There is a rapidly growing body of published ecosystem principles and management goals, both in the peer reviewed literature and in national and international resource management policy documents, to guide management of human activities in the natural environment in a way that recognizes ecological and ecosystem considerations.

These can be conveniently organized within a management framework that comprises four levels:

- Ecosystem principles;
- Management goals;
- Strategy required to achieve management goals; and
- Management and scientific activities (including monitoring) in support of implementing management policy

Below we describe some of the previously published material under these four headings, alongside relevant sections of the Convention text.

2.2.2.1 Ecosystem Principles

Aquatic ecosystems should be managed to ensure long-term sustainability of native fish stocks (Olver et al. 1995). This sustainability requires protection of specific physical and chemical habitats utilized by the individual members of that stock and maintenance of its supporting native community. In addition, vulnerable, threatened, and endangered species must be rigidly protected from all anthropogenic stresses.

Harwell (1997) states that we must recognize that humans are part of ecosystems and that they shape and are shaped by the natural system — that is, the sustainability of ecological and societal systems are mutually dependent. Mangel et al (1996) point out that maintenance of healthy populations of wild living resources in perpetuity is inconsistent with unlimited growth of human consumption of and demand for those resources.

2.2.2.2 Management goals and objectives

Pitcher and Pauly (1998) and Pitcher (2000) contend that rebuilding ecosystems, not sustainability, is the appropriate goal for fishery management. Mangel et al. (1996) establish a general rule that, to secure present and future options by maintaining biological diversity at genetic, species, population and ecosystem levels; neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation.

Grumbine (1994) provides five goals for ecosystem-based management of the oceans within the broader goal of maintaining ecosystem integrity:

1. to maintain, throughout the ocean realm, viable populations of all native marine species in functioning biological communities;
2. to include, within a spectrum of protected areas, representatives of all marine habitat types across their natural range of variation;
3. to maintain ecological processes in all ocean areas, including water and nutrient flows, community and trophic structures, ecosystem linkages and their annual and longer-term natural cycles, and the movement of broad-ranging and migratory species;
4. to ensure recognition that ecosystems are dynamic and that management must be at spatial and temporal scales that maintain the evolutionary potential of marine biological diversity;
5. to accommodate human uses of the oceans and the economic, social and cultural aspirations of people, within these constraints.

Holt and Talbot 1978 assert that the ecosystem should be maintained in a desirable state such that:

1. consumptive and non-consumptive values could be maximized on a continuing basis;
2. present and future options are ensured; and
3. the risk of irreversible change or long-term adverse effects as a result of use is minimized.

Additionally, May *et al* (1979) suggest that populations [other than those at the top of the trophic ladder] should not be depleted to such a level that their productivity or that of other species dependent upon them is significantly reduced.

Goals similar to these are enshrined in Article 2 of the CCAMLR Convention, which, even though it was signed as far back as 1980, remains the one of the most explicit articulations of ecosystem based objectives in international fisheries agreements in force. Article II of the CCAMLR Convention sets our principles of conservation, including:

- the maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels above those that ensure stable recruitment[5]; and

- the prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources.

2.2.2.3 Strategy to achieve management goals

Holt and Talbot (1978) recommend that management decisions should include a safety factor to allow for the fact that knowledge is limited and institutions are imperfect. Also, survey or monitoring, analysis, and assessment should precede planned use and accompany actual use of wild living resources. The results should be made available promptly for critical public review. May, et al (1979) recommend that harvesting levels should be set conservatively to safeguard against the combined effects of environmental variation and harvesting.

In this regard, the WCPFC Convention states that:

- The Commission shall adopt measures to minimise waste, discards, catch by lost or abandoned gear, and pollution originating from fishing vessels (Article 5(e)).

- The Commission shall adopt measures to minimise catch of non-target species, and impacts on associated or dependent species, in particular endangered species (Article 5(e)).

- The Commission shall adopt measures to protect biodiversity in the marine environment (Article 5(f)).

- Non-target species or associated or dependent species for which the status is of concern shall be subject to enhanced monitoring in order to review their status and the efficacy of conservation and management measures (Article 6(4)).

- If a natural phenomenon has a significant adverse impact on the status of highly migratory fish stocks, the Commission shall adopt conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate such adverse impacts (Article 6(6)).

- The Commission shall adopt, where necessary, conservation and management measures and recommendations for non-target species and species dependent on or associated with the target stocks, with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened (Article 10(1c)).

2.2.2.4 Management and scientific activities

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[5] clarified as meaning that the population size should not be allowed to fall below a level close to that which ensures the greatest net annual increment

As is articulated in many international agreements, Harwell (1997) emphasizes the need to integrate the best science available into the decision-making process, while continuing scientific research to reduce uncertainties. Mangel *et al*. (1996) propose that the full range of knowledge and skills from the natural and social sciences must be brought to bear on conservation problems. In addition, Assessment of the possible ecological and sociological effects of resource use should precede both proposed use and proposed restriction or expansion of ongoing use of a resource.

With respect to management and scientific activities in support of an ecosystem approach to management, the WCPFC Convention refers to:

- Promotion of the development and use of selective, environmentally safe and cost-effective fishing gear and techniques (Article 5(e)).

- Assess the impacts of fishing, other human activities and environmental factors on non-target species, and species belonging to the same ecosystem or dependent upon or associated with the target stocks (Article 5(d)).

- Take into account uncertainties relating to the impact of fishing activities on non-target and associated or dependent species, as well as existing and predicted oceanic, environmental and socio-economic conditions (Article 6(1b)).

- Develop data collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, and adopt plans where necessary to ensure the conservation of such species and to protect habitats of special concern (Article 6(1c)).

See Section 2.4.1 for additional guidance on monitoring activities.

2.2.3 Mitigating adverse effects of fishing on the ecosystem

When developing a management strategy that encompasses the guidance provided in Section 2.3, it is useful to consider two categories of problems: those that are more tractable and those that are less tractable. The more tractable ecosystem problems generally comprise the direct effects of fishing activity, other than those on the target species, such as bycatch and incidental mortality, and some direct effects on habitat. These direct effects are relatively easy to detect and can often be mitigated through some modification in the way fishing vessels operate or the configuration of the fishing gear. Well known examples include the use of streamer lines to reduce the capture of seabirds in longline fisheries, dolphin escape panels in tuna purse seines, and the use of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) in shrimp trawls.

The term “more tractable” is not meant to imply that these types of problems and their solutions are straightforward issues. Many of the mitigation techniques now being used have taken several years to develop and are still evolving. What makes these problems more tractable is that the relationship between cause and effect is relatively clear, i.e. it is clear that the fishing activity is the cause of the problem (for example when seabirds are caught on longlines). Although fishery managers have been generally aware of these types of problems for some time, it is only more recently, through the use of enhanced monitoring techniques (e.g. observers), that it has been possible to quantify them and monitor the implementation of viable solutions.

The common thread that identifies the less tractable problems is that they involve indirect effects of fishing, where cause and effect may be several steps removed from each other. This tends to introduce complications into the picture, because the fishery may not be the only, and perhaps not even the major cause of the problem. There is therefore a much higher level of uncertainty regarding the role played by the fishery in affecting the ecosystem properties in question. Finding ways to mitigate these problems is therefore very difficult.

We can demonstrate the difference between these less tractable problems and the more tractable problems by looking at a single example of an endangered species (e.g. a turtle, marine mammal or bird) with declining population size. The first response in such a situation would normally be to address more obvious issues such as direct mortality. As indicated previously, with modern monitoring tools it is relatively straightforward (although potentially expensive) to determine the extent of direct mortality. Once shown, methods can usually be found to mitigate against it; gear modifications, seasonal closures, closed areas etc. This can be regarded as a tractable problem. However, consider the situation where the direct mortality problem has been solved (and has been shown to be, through monitoring) but the endangered population continues to decline, or at least not recover. It then becomes necessary to look for other explanations, including the possibility that the fishery is having a different, indirect effect that is contributing to the failure of the endangered species to recover. This is clearly a much less tractable problem.

To date, much of the effort applied to incorporating ecosystem considerations into fisheries management has been applied to addressing the more tractable problems. This is, in part, because they are relatively easier to identify, and usually easier to mitigate. However, fisheries management in a truly ecosystem context involves substantially more than just, for example, modifying the operation of fishing gear to reduce undesirable interactions. In its fullest sense, managing for ecosystem considerations must address both more tractable and less tractable problems in a fully integrated sense within the analytical process that generates scientific advice for managers. The less tractable problems are those for which the cause and effect are much more difficult to demonstrate. These include the effects of human intervention (of which fishing may be only part) on complex species interactions that propagate through the food web with unpredictable results, and the influence of regime shifts (both short and long term) on factors that affect the way in which we look at population dynamics, such as natural mortality (for example, due to changes in species interactions), carrying capacity and stock-recruitment processes.

As described in Section 2.2.1, if the goal of management is to transition from an implicit to an explicit treatment of ecological and ecosystem effects of fishing within the management framework, the best way to proceed is in stages of increasing complexity, as illustrated in Figures 3 to 5. In Figure 4, the management process takes into account environmental effects in a more direct fashion in consideration of the status of the target stock and incorporates measures for more tractable ecosystem problems. This is the first level at which the assessment and management process really begins to embrace explicitly the ecosystem approach. In Figure 5, the integration of the environment, target stock, and its predators and prey into the assessment allows the less tractable ecosystem problems to be addressed.

2.3 Selection of national strategies for ecosystem based management of fisheries

2.3.1 Pacific Island Countries[6]

Several Pacific Island countries now have formal fisheries management plans that may include some policies regarding bycatch and ecosystem issues in general. Few, if any reached the stage of actually implementing ecosystem provisions in fisheries management. However, on behalf of its member countries, SPC has considered the types of research that might be required to support ecosystem approaches to management. Two approaches are currently being followed: a

[6] Information for PNG, Vanuatu and Tonga provided by Adam Langley, SPC Scientist

project funded by GEF that aims to describe the ecosystem, concentrating on trophic dynamics, of the so-called western Pacific warm pool large marine ecosystem, and an attempt to model the effects of the environment (particularly ENSO variability) and trophic dynamics on the target tuna species in a "bottom up" type approach (see Section 2.4.2.1).

Within the countries of the Pacific Community, there are currently Tuna Management Plans in place for Fiji, Palau, Papua New Guinea, Solomon Islands, Tonga, and Vanuatu. Most Plans generally include some over-arching goal regarding management of associated and dependent species. The relevant sections from three of the Plans are provided below. These examples are typical of the details of the other Plans although the relative emphasis on the main issues varies between plans, as does the level of detail on specific issues.

Among the management strategies adopted under the **Papua New Guinea** Management Plan, is the need to monitor the impact of tuna fishing on associated or dependent species and, where necessary, adopt measures to ensure sustainable management.

The **Tonga** Plan includes the goal of minimising any adverse impacts of tuna fishing on the marine environment and non-tuna species. The principles established in the FAO Code of Conduct for Responsible Fisheries will be used to guide the design and implementation of strategies under the Tuna Plan, including...promoting management measures that ensure conservation of species belonging to the same ecosystem or associated with or dependent upon the target species. The plan aims to minimise adverse impacts of fishing on marine environment and bycatch species. Regarding the latter, all licensed vessels must provide all required details of the catch of all species and disposal of the catch as part of logbook data. The Tongan Ministry of Fisheries must compile information provided on by-catch species and make this available to industry on an annual basis. The Ministry, in consultation with the TCC, must also implement appropriate measures to control or limit catch of bycatch species, if required. Logbook information must specify whether a catch is taken in association with a Fish Aggregation Device (FAD), whether naturally occurring or artificial, drifting or moored.

In regard to the incidental capture of turtles, seabirds and marine mammals Tonga requires the Master and crew to make all efforts to release all such animals alive. Where possible, sharks that are not utilised for consumption or sale must also be released alive. Finning of live sharks is prohibited.

In **Vanuatu** the Fisheries Division monitors by-catch taken in the tuna fishery through its Observer Programme and catch reporting by all commercial fishing vessels. Where necessary for conservation purposes, the Government of Vanuatu has the option to use management actions that limit or eliminate by-catch, including, but not limited to, imposing closed areas, closing the fishery for certain periods, and limiting gear types. Of particular concern to Vanuatu is the by-catch of billfish and other game species, sharks, marine mammals, turtles, and birds. The by-catch of tuna in fisheries targeting other species should also be monitored these fisheries may also be subjected to management actions to limit tuna interception.

The management of tuna fisheries in Vanuatu also recognises the importance of seamounts and other areas considered to be important for sustaining the biodiversity and natural resources of Vanuatu waters. Closed areas specified in the Schedules to the Tuna Management Plan or other regulations will protect areas that are considered to be of special biological importance.

2.3.2 Australia

The Fisheries Management Act 1991 gives the Australia Fisheries Management Authority (AFMA) the charter to "ensure that the exploitation of fisheries resources and the carrying on of any related activities are conducted in a manner consistent with the principles of ecologically sustainable development and the exercise of the precautionary principle, in particular the need to have regard to the impact of fishing activities on non-target species and the long term sustainability of the marine environment". The Environment Protection and Biodiversity Conservation Act (1999), which took effect in July 2000, further requires all AFMA managed fisheries to be assessed for their "ecological sustainability".

AFMA pursues ecologically sustainable development by managing for sustainable fisheries and for the benefit of all current and future users and interest groups. AFMA considers that this requires that fishing occurs in such a way that:

- resources are able to renew themselves;
- the environment can sustain the activities being carried out; and
- the impact of fishing does not threaten biological diversity.

The National Strategy for the Conservation of Australia's biological diversity was agreed by the Commonwealth, State and Territory Governments in 1996. It explicitly recognises and accepts the guiding principles of Australia's National Strategy for Ecologically Sustainable Development. The National Strategy for the Conservation of Australia's Biological Diversity deals with all of Australia's biodiversity - terrestrial and aquatic — and is the agreed basis for achieving conservation of the biodiversity in Australia's oceans. The goal of this strategy is to protect biodiversity and maintain ecological processes and systems. To achieve this it provides a comprehensive set of objectives and actions. Ward et al. (1997) paraphrased the key objectives of the strategy, as they relate to marine biodiversity, as follows:

- Identify biodiversity components and threatening processes.
- Manage on a regional basis, using natural borders.
- Improve standards of management and protection through integrated management.
- Establish and manage a comprehensive, adequate and representative system of protected areas.
- Strengthen off-reserve conservation of biodiversity.
- Enable threatened species and communities to thrive in their natural habitats, and prevent additional species and communities from becoming threatened.
- Use ecologically sustainable fisheries management practices.
- Use ecologically sustainable management practices for tourism and recreational activities.
- Monitor, regulate and minimise activities that have adverse impacts on biodiversity and be able to respond appropriately in emergencies.
- Control the introduction and spread of alien and genetically modified organisms and the spread of native species beyond their natural range.
- Minimise the impacts of pollution.
- Minimise the impacts of anthropogenic climate change on biodiversity.
- Repair and rehabilitate degraded areas.
- Assess and minimise the potential impacts of government projects, programs and policies on biodiversity.
- Provide the knowledge and understanding needed for effective conservation and management of biodiversity.
- Increase public awareness and involvement with biodiversity and its management.
- Implement the National Strategy for the Conservation of Australia's Biological Diversity within established time frames.

Regarding implementation, according to Ward et al. (1997), in 1997 the existing legislative, organisational and administrative arrangements for management of the oceans in Australia were fragmented and lacked a strategic and integrated approach to conserving the ocean's biodiversity. To be effective and accountable, a major shift from the current independent management by sectors was required. It was recommended that the new ocean management arrangements must include overarching comprehensive regional objectives for biodiversity, integrated into regional ecosystem-based management within a national framework and incorporated into sectoral arrangements.

2.3.3 United States

The Magnuson-Stevens Fishery Management and Conservation Act of 1996 (M-S Act) required that the National Marine Fisheries Service (NOAA Fisheries) prepare a report to Congress on the issue of ecosystem-based management. The Report concluded (NMFS 1999) that the key to an effective ecosystem approach is to fish more conservatively: "The depressed condition of many U.S. stocks is related primarily to unsustainable levels of fishing effort, rather than ecosystem effects. With few exceptions, scientists understand the levels of fishing effort required to produce sustainable yields, but fishery managers are challenged by a highly politicized process to exceed those levels for short-term gains. Setting maximum sustainable yield and optimum yield conservatively, and respecting these conservative goals in the face of political and economic pressure is essential in any ecosystem approach."

The Report pointed out that single species or species complex management should continue as a basic tool for the foreseeable future. However, this necessary approach is not sufficient to implement an ecosystem approach. The report recommended the development of a Fisheries Ecosystem Plan (FEP) that would mimic the existing Fishery Management Plans under which U.S. fisheries are currently managed. The FEP would have the following components:

1. <u>Delineate the geographic extent of the ecosystem under consideration.</u> This will include an evaluation of the land-water interface as well as circumscribing the most important spatial relationships amongst species

2. <u>Develop a conceptual model of the food web.</u> This can often be done, but has difficulties because the same individual, at different times in its life plays different roles in the food web. Pitcher and Hart (1982, pg. 37) show how herring interact with different members of the plankton, depending upon the age of the individual herring. In other cases, the sheer numbers of species involved makes creating a food web difficult. For example, the eastern Bering Sea fishery involves more than 15 species of flatfish, 20 of rockfish, and 4 of roundfish, plus squid (Francis *et al*. 1988, pg. 190). One solution, consistent with Fager's notion of communities as recurrent groups, is to focus on species assemblages (e.g. Rothschild *et al*. 1997, pg. 148). Another is to draw webs of increasing complexity (Mangel 1988, pg. 90-91). This task needs to focus on the primary interactions between the fishery and components of the food web and the possible interactions that might provide feedbacks to the primary interaction (see Yodzis 2000).

3. <u>Describe the habitat needs of different life history stages of the organisms in the "significant food web" and how they are considered in conservation and management measures</u>.

4. <u>Calculate total removals -- including incidental mortality -- and show how they relate to standing biomass, production, optimum yields, natural mortality, and trophic structure</u>.

5. <u>Assess how uncertainty is characterized and what kind of buffers against uncertainty is included in conservation and management actions</u>.

6. <u>Develop indices of ecosystem health as targets for management</u>.

7. <u>Describe available long-term monitoring data and how they are used</u>. At this stage, an evaluation of habitat condition, oceanographic variability, potential confounding influences (e.g. terrestrial, freshwater, waste disposal) and scales of interactions among these factors need to be described and the overall status of the system related to the targets for management.

8. <u>Assess ecological, human, and institutional elements of the ecosystem that most significantly affect fisheries</u>. Based on the recent experience in other fora, attention needs also to be given to evaluation of the spatial and temporal manifestations of

effects. This is required to verify that the assessments, management decisions and future monitoring activities account for the types of effects that might arise and whether the management system is able to respond to these before irreversible changes occur.

The North Pacific Fishery Management Council, one of the eight regional fishery management councils established under U.S. fisheries legislation, established an Ecosystem Committee in 1996. This committee has developed a draft policy for ecosystem-based management of North Pacific fisheries, based on principles and elements of ecosystem management from the scientific literature (e.g. Grumbine 1994, Mangel *et al*. 1996; Christensen *et al*. 1996). The following draft was reported in Witherell et al. (2000), and to date has not changed (Witherell pers.comm.)

Definition:

Ecosystem-based management, as defined by the NPFMC, is a strategy to regulate human activity towards maintaining long-term system sustainability (within the range of natural variability as we understand it) of the North Pacific, covering the Gulf of Alaska, the Eastern and Western Bering Sea, and the Aleutian Islands region.

Objective:

Provide future generations the opportunities and resources we enjoy today.

Goals:

1. Maintain biodiversity consistent with natural evolutionary and ecological processes, including dynamic change and variability.
2. Maintain and restore habitats essential for fish and their prey.
3. Maintain system sustainability and sustainable yields of resources for human consumption and non-extractive uses.
4. Maintain the concept that humans are components of the ecosystem.

Guidelines:

1. Integrate ecosystem-based management through interactive partnerships with other agencies, stakeholders, and public.
2. Utilize sound ecological models as an aid in understanding the structure, function, and dynamics of the ecosystem.
3. Utilize research and monitoring to test ecosystem approaches.
4. Use precaution when faced with uncertainties to minimize risk; management decisions should err on the side of resource conservation.

Understanding:

1. Uncontrolled human population growth and consequent demand for resources are inconsistent with resource sustainability.
2. Ecosystem-based management requires time scales that transcend human lifetimes.
3. Ecosystems are open, interconnected, complex, and dynamic; they transcend management boundaries.

2.3.4 United Kingdom

The UK Joint Nature Conservation Committee (JNCC)[7] considers that a fully comprehensive ecosystem-based approach would require taking account of, *inter alia*, all the interactions the target fish stock has with predators, competitors and prey species; the effects of weather and

[7] The JNCC is the UK Government's wildlife adviser, undertaking national and international conservation work on behalf of the three country nature conservation agencies English Nature, Scottish Natural Heritage and the Countryside Council for Wales

climate; the interactions between fish and habitat; and the effects of fishing on species and habitat (JNCC 2002). Such complete understanding of ecosystems is unlikely to be achieved, and there is a need for pragmatism. Ecosystem-based management is not an instant replacement for traditional fisheries management - rather it should be seen as an evolution of the existing systems.

Therefore, progress towards the goal is likely to be made in an incremental way rather than overnight and it is possible to identify the steps towards, and desirable characteristics of, ecosystem-based fisheries management, including:

1. The identification of the relevant ecosystems, and their boundaries and characteristics;
2. The agreement of management objectives for each ecosystem. These should encompass wider ecosystem factors and not just the target stock, and all stakeholder groups should be involved in their development;
3. Long-term management objectives should be developed as well as short to medium-term objectives;
4. The establishment of sustainability indicators (including reference points, targets and limits) and the accompanying monitoring;
5. A decentralised regional approach to fisheries management in EU waters should be adopted enabling management measures to be taken that are appropriate to biologically distinct areas. These could include technical measures, spatial management (including closed areas), effort-related controls and systems of access rights;
6. Their should be better tailoring of research and information provision to support the ecosystem approach, including better knowledge of ecosystem interactions, and of fishing-related impacts, and also improved monitoring bycatch and discards to include information of non-commercial bycatch;
7. Application of Adaptive Management and the Precautionary Principle given the degree of uncertainty and dynamics of the ecosystem;
8. An effective enforcement capability.

Furthermore, fisheries management should not be seen in isolation from the wider management of the marine environment. Over time, fisheries management will need to become much better integrated with other sectors of marine management (JNCC 2002).

2.4 Data and research requirements

2.4.1 General guidance

Taking into account ecosystem considerations in the management of fisheries requires substantial amounts of data on target species, interactions between target species and other species, food webs, and the direct effects of fishing on non-target species and their habitat. For example CCAMLR, an organisation with perhaps the longest track record in ecosystem based management, has established the CCAMLR Ecosystem Monitoring Programme (CEMP), the results of which are analysed and discussed by the Working Group on Ecosystem Monitoring and Management (WG-EMM)[8].

To meet the objectives of the WCPFO Convention will require substantial input into modelling and monitoring of not just target fisheries, but the environment in which they exist. An ecosystem approach to management requires the following components:

1. Specification of clear operational objectives, including performance criteria for evaluating management procedures and actions. Examples of such objectives include:

    - species-oriented objectives (for example, by how much can the probability of collapse of the stock be altered?);
    - habitat-oriented objectives (for example, how much habitat is required to remain unaltered?);
    - trends or shifts in state variables (for example, what deviations in environmental state variables can occur before considering the system has changed from its current state and a re-evaluation of the monitoring programme and catch controls is required?); and
    - process-oriented objectives (for example, how much change in ecosystem productivity can be tolerated before changes in the distribution of production between the fishery and the ecosystem need to be made?)

2. Prospective evaluation of the management procedures, which includes fishing controls, monitoring, and decision rules for altering fishing controls or monitoring, to determine those which satisfy the performance criteria.

The discussion above highlights the need to monitor different aspects of the predator-prey system to determine the role of fishing in causing changes to ecosystem properties. A carefully designed monitoring program can also be used to determine the extent to which fishing may need to be reduced to achieve recovery of populations, and to signal when changes to fishing controls may be required.

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[8] CEMP has two central aims: (1) to detect and record significant changes in critical components of the ecosystem to serve as a basis for conservation, and (2) to distinguish between changes due to harvesting of commercial species and changes due to environmental variability. To meet Aim 1, selected life history parameters such as abundance, distribution, feeding, reproduction, growth and condition are monitored for designated predator species, which are likely to reflect changes in the availability of harvested prey species, such as krill. Currently, monitored species include crabeater and Antarctic fur seals, four species of penguins, the black-browed albatross and two species of petrels. Monitoring is carried out by Member states at specially designated sites. To contribute towards Aim 2, prey species, environmental factors, and the links between these and predators are monitored. To mitigate against the difficulties imposed by the high level of complexity of the ecosystem, CCAMLR has adopted a strategic modelling approach. This uses computer simulation as a key tool in setting scientific priorities and developing management options. The aim is not to develop a comprehensive ecosystem model, but rather to develop simpler models for strategic purposes, which capture important features of the ecosystem, whilst recognising the multiple linkages, which exist between components.

Ideally, the scale and resources applied to a monitoring program are commensurate with the value of the fishery and the program provides the information necessary for making decisions that are "correct" within the acceptable bounds of making Type I and II statistical errors. In fisheries terms, these errors are translated, respectively, into those that cause a reduction in fishing when it was not justified (Type I) and those that cause environmental harm when fishing should have been more effectively controlled (Type II). The precision of monitoring (replication) needs to be such that these errors are kept within acceptable bounds.

The most important element of the monitoring program is to determine the measures of the environment that will lead to the most appropriate management action. That is, one must identify the variables of interest, the magnitude of change or difference in those variables that would warrant action and the temporal scale on which management decisions need to be made. For example, managers would ideally prefer to receive feedback on the scale of one to two years concerning how to manage fisheries when faced with a possible impact on a threatened or endangered species, rather than obtaining feedback over a longer period, say 10 years. Information on population abundance is unlikely to provide such information in that time frame, even in the absence of fishing.

2.4.2 Selection of existing research programs

2.4.2.1 Oceanic Fisheries Program of SPC

The Tuna Ecology and Biology (TEB) section of the OFP undertakes analyses to understand the biological parameters and the environmental processes that influence the productivity of tuna and billfish populations. Biological investigations focus on tuna and billfish age and growth, on tuna movement and behaviour as observed from classical or electronic data archiving tags, and on tuna and billfish diet in a more general study devoted to the food web of the pelagic ecosystem. Besides the field sampling and laboratory analyses, mathematical models are developed to understand the environmental determinants of tuna fishery production, including impacts of climate fluctuation (El Niño Southern Oscillation, Pacific decadal Oscillation and global warming). There is also increasing interest in other components of the ecosystem which supports the tuna fishery, and impacts of fishing on them.

SPC has two complementary approaches that are also strongly linked to stock assessment modelling:

- A GEF project, now extended with a project funded by the Pelagic Fisheries Research Programme[9], titled *"Trophic structure and tuna movement in the cold tongue-warm pool pelagic ecosystem of the equatorial Pacific"* [10] (Allain V., Olson R., Galvan Magaña F., Popp B., Fry B.), has the objective of describing the trophic structure of the ecosystem, both in term of species interactions (diet analyses) and transfer of energy through the trophic levels (isotope analyses). Results will be used in ecosystem modelling.

- A one-dimensional ECOPATH-ECOSIM model will use the diet analyses results while the spatial SEPODYM model will use the isotope results. This latter model has been developed to investigate the environmental (climate) effects on the spatio-temporal dynamics of tuna and associated species and their fisheries.

These different studies are linked to a more general framework defined as the "Oceanic Fisheries and Climate Change Project (OFCCP)[11] of the international GLOBEC program. Started in 2002, the goal

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[9] http://www.soest.hawaii.edu/PFRP/biology/biology.html, Joint Institute for Marine & Atmospheric Research, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii 96822 USA, Program Manager Dr John Sibert.

[10] http://www.spc.org.nc/OceanFish/Html/TEB/EcoSystem/foodweb.htm

[11] http://www.spc.org.nc/OceanFish/Html/TEB/Env&Mod/OFCCP.htm , Contact: Patrick Lehodey, Oceanic

of the OFCCP is to conduct simulations with ecosystem models that include the main tuna species, using an input data set predicted under a scenario of climate change induced by greenhouse warming. This should lead to the first tentative understanding how greenhouse warming will affect, at the ocean and global scales, the abundance and productivity of marine populations in the pelagic ecosystem, focusing on the major exploited species and fisheries, by a real coupling between atmospheric, oceanic, chemical and biological processes. Potential feedbacks from the changes in the pelagic ecosystem, and socio-economical consequences will be investigated to propose adaptation measures for the future.

Four major components have been identified to achieve the objectives of the project:

- Monitoring the upper tropic levels of the pelagic ecosystem

It is proposed in the present project to use existing technologies, and also to develop new instrumentation for monitoring the upper trophic levels of the pelagic ecosystem. Observation will combine both extensive studies at ocean basin-scale and intensive studies in some sub-areas and key sites. Extensive studies aim at building ocean data sets for micronekton biomass and large pelagics biomass or individual records, using acoustic (micronekton biomass), sonar (tuna biomass), and electronic tracking (individuals) devices. Intensive studies will focus on important processes and behavior (e.g., prey-predator interaction, habitat, schooling and aggregation of tunas, reproduction, composition and dynamics of micronekton, etc).

- Food web structure in pelagic ecosystems

Production at higher trophic levels (usually exploited species) depends on the production at lower levels (bottom-up control) and may be modulated by the physical forcing and the structure of the marine food webs. Ecological concepts suggest for instance that the structure of the food web can be controlled by the biodiversity within the system and/or by higher predators (top-down control). However, concerning pelagic ecosystems, there is very little observation to illustrate such controls. In association with the data collected by the monitoring component of this project, it is essential for modelling the pelagic ecosystem to identify the functional groups, how energy and matter flow through these groups and how they are affected by physical and biological changes as well as by human activities (fisheries).

Two kinds of analyses will be helpful in this task. A classical approach based on the study of stomach contents to establish the prey-predator interactions, and the more recent isotope-ratio approach, that appears a promising way for describing the energy transfer through the food web. The success of these approaches also relies on the multiplicity of studies in different regions of the ocean(s) and in different periods of time. The comparative study necessitates developing standardized protocols, reference databases and controlled laboratory experiments. Retrospective analyses based on the numerous diet studies published or still in archives of many institutes should be also encouraged. Information obtained from these studies and from the monitoring will be used in individual energetics models (IBM), mass-balance models (ECOPATH-ECOSIM) and spatial ecosystem models (SEPoDyM [12]).

SEPoDyM (Spatial Environmental POpulation DYnamic Model) has been developed to explore the underlying mechanisms by which the environmental variability affects the pelagic ecosystem and tuna populations. The model is a basin-scale, 2D coupled physical-biological interaction model, combining a forage (prey) production model with an age structured population model of targeted (tuna predator) species and their fisheries. The model contains environmental and spatial components used to constrain the movement and the recruitment of tuna. The skipjack tuna population and fisheries are the first described in SEPoDyM. Three different fishing gears are described: purse-seine, pole-and-line and a group of mixed domestic gears from the Philippines and Indonesia. A total of ten fleets are represented, each with separate catchability coefficients.

Fisheries Programme, SPC, Noumea, New Caledonia

[12] http://www.spc.org.nc/OceanFish/Html/TEB/Env&Mod/Sepodym.htm

An age-based selectivity function is used for each gear. Fishing effort of each fleet vary by month and in space, with a one degree square resolution except for the Philippine and Indonesia fleets that provide data aggregated by five degree square, and year. The catchability coefficients are scaled to obtain estimated catches at the same level as observed catches. Results of the simulation are compared to observed fishing data by fleets, such as total monthly catch, spatial distribution of catch, and distribution of length frequencies.

- Modeling from ocean basin to individual scale

Close association between observation and modeling has been a permanent guide in conceptualization of this project. Recognizing the diversity of space-time scales processes overlapping in pelagic ecosystem dynamics, a second key idea is that a general framework is needed to integrate studies at different time and space scales with potential connections between them. There is a large range of models represented in the project covering global to individual scales. At global or basin scales, predictions from three different coupled physical-biogeochemical models will be used over the period 1950-present. The global model will also provide predictions for the next century using a scenario of greenhouse warming. These predictions will be used to run the ecosystem models of upper trophic levels on which the economical and social analyses rely. At least one of the physical-biogeochemical models should provide prediction at high resolution in one or a few identified sub-regions where intensive process studies are conducted. A similar approach will be investigated for the spatial ecosystem models. This would allow connections between large and small scales (low and high frequencies) processes and testing the mechanisms that control the system when moving from one scale (frequency) to the other.

- Socio-economical impacts

The interannual climate variability due to ENSO events has important socio-economic impacts on tuna fishery and industry at the global scale, that in turn may affect the tuna populations (e.g., higher/lower catch) and the pelagic ecosystem (by-catch, interaction between species, top-down effects). Several causes drive the fluctuations of tuna stocks and catches. While economic rather than biological reasons limit (today) the catch increase of the most productive tuna species (skipjack) in the Pacific, the intense fishing effort on the highly valuable bluefin tuna, perhaps combined with environmental forcing, has led to a decline in this population from the 1960's to the eighties.

Interactions amongst species and between the multiple and diverse fisheries, as well as potential cascade effects in the ecosystem raise important questions for management with potential strong socio-economic repercussions. Based on existing model, investigations of these interactions and effects occurring with ENSO would help to assess the vulnerability and impacts in a scenario of global warming, and to eventually propose adaptations and/or mitigation measures for the future.

2.4.2.2 Pelagic Fisheries Research Program

The following project summaries, which have relevance to the management of pelagic fisheries in the WCPO, were downloaded from the PFRP web site.

- *Investigating the Life History and Ecology of Opah and Monchong in the North Pacific.*

P.I.: Michael Seki, National Marine Fisheries Service, Honolulu Laboratory

Two miscellaneous pelagic fish species incidentally caught by Hawaii longline vessels targeting bigeye tuna are the opah and monchong. Particularly valued by restaurants, these exotic, deep-water fishes are generally harvested in small, but nevertheless significant quantities. Since

neither are targeted species, these fishes have historically been poorly studied and as a result available information pertaining to the biology and ecology of this resource are virtually non-existent.
The primary objective of this project is to investigate and define some of the fundamental life history and ecological characteristics of the opah and monchong resource in the North Pacific. The focus will be on the opah (moonfish), *Lampris guttatus*, and on two species of monchong (pomfret): the bigscale pomfret (*Taractichthys steindachneri*) and the lustrous pomfret (*Eumegistus illustris*). Project researchers will gather biological and ecological data through:

- a comprehensive collection of shoreside data and biological sampling,
- analysis and merging of fishing industry (NMFS observer and logbook, North Pacific driftnet, auction), research and environmental datasets, and
- capturing depth information collected from vessels of opportunity.

- *Trophic Ecology and Structure-Associated Aggregation Behavior in Bigeye and Yellowfin Tuna in Hawaiian Waters.*

P.I.: Dr. Kim Holland, Hawaii Institute of Marine Biology, University of Hawaii. Dr. Richard Young, Department of Oceanography, University of Hawaii. Dr. Richard Brill, National Marine Fisheries Service, Honolulu Laboratory. Dr. Laurent Dagorn, IRD HEA, France

The focus of this project is to elucidate the role of feeding ecology in the aggregation (schooling) behavior of tunas, especially those aggregations found around floating logs, FADs (fish aggregation devices) and seamounts. Not only are tuna aggregations a dominant component of worldwide tuna fisheries but understanding the biology of aggregation phenomena also has direct pertinence to stock assessment and to understanding the ecosystems that support the fishery. From a stock assessment perspective, the contributions of aggregations to the overall distribution of tuna biomass are central to estimating the size of the resource and the movements of the population. The occurence of several different types of tuna aggregation within close proximity to Hawaii, combined with the existence of other pertinent fishery research projects, provides an ideal setting for the research into the interaction between feeding behavior and aggregation behavior.

Two general approaches will be used: 1) "traditional" examination of stomach contents of captured tunas, and 2) analysis of different tuna tissues for stable isotopes of carbon and nitrogen. These methods provide wide-ranging and complimentary approaches for understanding trophic ecology of tunas.

- *Distributions, Histories, and Recent Catch Trends with Six Fish Taxa Taken as Incidental Catch by the Hawai'i-based Commercial Longline Fishery.*

P.I.: Dr. William A. Walsh, National Marine Fisheries Service, Honolulu Laboratory. Dr. Samuel Pooley, National Marine Fisheries Service, Southwest Fisheries Science Center

Project investigators will conduct comprehensive statistical research into the geographical distributions, histories, and recent catch trends of six fish taxa sometimes characterized as non-target or incidental catch in the Hawaii-based commercial longline fishery. An understanding of species distributions is needed to assess the likely effects of management policies (e.g., area closures) instituted in response to requirements of conservation law. Accurate catch rate histories are required to evaluate fishery trends and stability of individual species, and to identify statistical relationships between catch rates and extrinsic factors that might be masked (or created) by false or erroneous data. The fishes of interest to this project together comprised almost half (43.4%, numerical basis) of the catch of the Hawaii-based longline fleet from January 1991 through December 1998 (Walsh, unpublished data):

- Blue shark (*Prionace glauca*)
- Dolphin fish, or "mahi mahi" (*Coryphaena hippurus*)
- Blue marlin (*Makaira nigricans*)
- Moonfish, or "opah" (*Lampris guttatus*)
- Wahoo, or "ono" (*Acanthocybium solandri*)
- Three species of pomfrets: Pacific pomfret (*Brama japonica*), bigscale pomfret (*Taractichthys steindachneri*), and dagger pomfret (*Taractes rubescens*)

Project researchers will examine data gathered by the Hawaii Longline Observer Program (National Marine Fisheries Service), logbook records submitted by the Hawaii-based longline fleet, and sales records from public fish auctions conducted at the United Fishing Agency (UFA) in Honolulu, Hawaii. As in previous data comparison studies researchers hope to identify the specific factors that distort historical catch trends (e.g. mis-identification, under-reporting). Researchers also plan to develop a generalized additive model (GAM) to address the issues of possible data inaccuracies.

- *Pop-Off Satellite Archival Tags to Chronicle the Survival and Movements of Blue Sharks Following Release from Longline Gear*

P.I.: Dr. Michael Musyl, Dr. Richard Brill, National Marine Fisheries Service, Honolulu Laboratory.

Recent advances in electronic data storage technology have made it possible to construct devices that allow the long term (months to years) recording of detailed records of the vertical and horizontal movements of fishes. These "archival" tags are carried inside the fish and record data on geographical position, ambient light levels, swimming depth and temperature (internal and external). Further design refinements have also made it possible for fine-scale environmental and daily geolocation data to be downloaded via satellites with "pop-off" satellite archival tags (PSATs). These PSAT tags are released from the fish at a specified period and/or threshold depth, allowing for immediate access to recorded time-series data.

During the course of this three-year project, researchers plan to attach PSATs on up to 50 blue sharks captured and released from commercial longline gear. Researchers anticipate the majority of sharks to be tagged on dedicated longline cruises aboard the NMFS research vessel *Townsend Cromwell* and while onboard commercial longline vessels. Researchers will attach hook timers to longline droppers to record the duration of hooking prior to subsequent release. Researchers hope to have tags equipped with a "safety valve" feature to insure that collected data are not lost. This will consist of a glass link that will crush at a precisely specified depth. That is, if the fish sinks and dies, at about 800 m (before the float implodes), the glass link will break and allow the tag to float to the surface.
Project researchers' plan to use PSATs to study the horizontal and vertical movements, and distribution of blue shark is intended to provide critical knowledge in three areas:

1. Daily horizontal and vertical movement patterns, depth distribution, and effects of oceanographic conditions on the vulnerability of blue sharks to longline fishing gear.
2. The survival rates of blue sharks captured and released from commercial longline gear.
3. Stock identification, dispersal, and possible fishery interactions.

- *Developing Biochemical and Physiological Predictors of Long Term Survival in Released Blue Sharks and Sea Turtles.*

P.I.: Dr. Christopher Moyes, Department of Biology, Queen's University, Kingston, Ontario

For catch-and-release sports fishing and non-retention of commercially caught non-target species to be justifiable management options, there must be a reasonable likelihood that released animals will survive long term. At present, there is no scientific basis for making this prediction for any large pelagic fish. Therefore, even when recreational anglers and commercial fishermen practice good catch-and-release fishing, high rates of delayed mortality are a distinct possibility. Tag-and-release programs are important tools for assessing post-release survival, but they can be difficult and expensive. Management strategies intended to minimize mortality of non-target species depend upon accurate information on post-release survival. Fisheries researchers recognize that many factors (e.g., size, sex, reproductive state, water temperature, fight time, fishing gear) may influence the likelihood of mortality. Consequently, conclusions from tag-and-release studies are rarely extrapolated to other species.

Rather than assessing how many fish survive, project investigators will research why fish die. Project researchers believe that delayed mortality is probably not a direct result of immediate metabolic pertubations but rather more likely due to irreversible cellular damage. Researchers will analyze tissue and blood samples from blue sharks and sea turtles to develop a set of diagnostic tools to assess the biochemical and physiological status of fish caught by longline gear on scientific cruises. Once a set of tools has been developed researchers will be in a position to use blood samples to assess a broad spectrum of parameters which collectively address the extent and nature of tissue damage in response to physiological stress of capture. These tools will be used in combination with pop-off satellite archival tag data to establish correlates of survival or mortality. Researchers plan to develop such tools to maximize lateral transfer between species and anticipate eventually applying these techniques on other commercially important game fish and non-target species.

- *Population Biology of Pacific Oceanic Sharks.*

P.I.: Dr. Christofer Boggs, National Marine Fisheries Service, Honolulu Laboratory

Concerns about the status of shark populations are becoming an important issue in the management of the Hawaii-based longline fishery. Sharks are important and valuable catches in both foreign and U.S. longline fisheries targeting tunas and billfishes. The practice of finning sharks has also increased in recent years. In general, conservation organizations are seeking to ban shark finning and commercial shark harvests while commercial fisheries will resist these efforts. The need for a better understanding of the population biology of oceanic sharks is necessary before management decisions can be made. Stock assessments are required for all oceanic shark species under the U.S. Pelagic Fishery Management Plan for the central and western Pacific.

The objectives of this project are to address important information gaps regarding oceanic shark species (oceanic white-tip, blue shark, short-fin mako, thresher). Researchers on this project will review current literature and consult with other shark researchers to identify gaps in knowledge of life history and ecology of oceanic sharks impacted by North Pacific longline fisheries. The project P.I. will analyze shark biological samples and also share samples with other shark researchers. The project P.I. will obtain more information on: age and growth, reproduction and maturation, distribution and migration, and trophic relationships. Analysis of shark fins will be conducted to estimate sizes of sharks caught. P.I. will analyze effects of longline gear (hook depth, soak time) for application to catch-per-unit-effort analysis. Measurements of swimming depth, geographic movements and mortality rates of sharks will be obtained through the application of pop-up satellite transmitting archival tags (PSTATs).

3 Ecosystem issues of concern for tuna fisheries in the Western and Central Pacific

3.1 A conceptual framework

Although Articles 5 and 6 of the Convention make it clear that ecosystem effects should play a large role in shaping management measures for fisheries in the WCPO, there is not much language indicating what specific types of action might be taken. Article 5(e) refers to the promotion of the development and use of selective, environmentally safe and cost-effective fishing gear and techniques, but in order to meet the objectives set out in Articles 5 and 6, it may also be necessary to make adjustments to target species management measures (i.e. those in Article 10(2)) to avoid deleterious effects on the ecosystem.

As indicated in Section 2, a conceptual framework for considering the ecosystem effects of fishing must focus on three types of effects:

- incidental mortality of non-target species in fisheries operations;
- indirect effects on food webs; and
- direct effects on habitat.

Fishery management must also consider the effects of environmental fluctuation on the ability of models to predict the future effects of fishing on target populations. For example, environmental regime shifts may have profound effects on assumptions regarding growth rates, migration patterns and stock-recruitment relationships.

The following sections discuss these issues in more detail and specifically review their relevance to tuna fisheries in the WCPO.

3.2 Bycatch

The western and central Pacific Ocean currently supports the largest industrial tuna fishery in the world, with an estimated annual catches averaging about 1.5 million metric tons over the past decade. Skipjack is the most important of the four major tuna species in the fishery, accounting for well over half of the catch by weight, followed by yellowfin, bigeye and albacore. Purse seine gear is responsible for about 60% of the catch, with longline gear being the next most important, followed by pole-and-line gear and then troll gear.

All of these fisheries invariably have some level of catch of non-target species (bycatch). A portion of this bycatch is discarded because it has little or no economic value, and, if retained, would take up storage capacity best used for the more valuable tuna species. A portion of the target catch is also often discarded for economic reasons, or because it is damaged, physically too small for efficient processing, or lost because of gear failures during fishing operations.

Bycatch occurs in all fisheries. The term, however, has many meanings. Concerns with the terminology used to identify bycatch or discards were addressed at a bycatch workshop in Newport, Oregon (U.S.A) in February 1992 (McCaughran 1992). Alverson et al. (1994) used the following definition as proposed at the Newport Workshop:

- Target Catch — The catch of a species or species assemblage that is primarily sought in a fishery, such as shrimp, flounders, cods;

- Incidental Catch — Retained catch of non-targeted species;

- Discarded Catch That portion of the catch returned to the sea as a result of economic, legal, or personal considerations;

- Bycatch Discarded Catch plus Incidental Catch.

The amount and impact of the bycatch varies considerable by gear and area. At the time of the study by Alverson *et al*. (1994)[13], bycatch in the west and central Pacific Ocean area (FAO Areas 61 and 71) ranked as the third highest of the FAO statistical areas. Discards in shrimp fisheries (Thailand, Indonesia, and the Philippines) accounted for more than 50% of this total. However, discards associated with harvests of tuna added significantly to the regional total. The tuna-bonito-billfish fisheries annually discarded an estimated worldwide total of 0.7 million tons of a 4.2 million ton catch during the early 1990s. This is about 15% of the total catch, or 18% of the target catch. At the time, however, it was considered that this figure might increase as the proportion of fishing effort applied to purse seine sets on logs or other fish-aggregating devices (FAD) increases. While dolphin removals on log/FAD sets are much lower than when setting on dolphin pods, aggregate removals of other species are much higher.

The western and central Pacific tuna fishery takes over one hundred species, including commercial swordfish and striped marlin, sharks and various fish species (SCTB 1998). Incidental catches of marine wildlife, such as seabirds and turtles are reported to be rare in most areas, but those reports need to be verified. Many species, such as mahi mahi and wahoo, are important sources of food and income to Pacific island communities. Several Pacific island nations are also interested in developing their own commercial game fishing industries.

According to SPC[14], there remains a large degree of uncertainty about the impacts of tuna fisheries on by-catch species and pelagic ecosystems. However, it is obvious that these impacts have increased very significantly over the last 50 years as tuna fisheries worldwide have expanded their catches and effort by orders of magnitude. The problem is that we have little or no information on the relative abundances or biomasses of many components of the pelagic ecosystem.

Observer programs, conducted by regional and national organizations, have developed over the last two to three decades. In general, these observer programs were created to monitor activities such as compliance with licensing agreements and restrictions on incidental catches. In addition to providing information required for meeting those objectives, observer programs provide essentially the only reliable, detailed information on catches discarded at sea. Based on such observer programs in the WCPO the main by-catch species of tuna fisheries are billfish, sharks, Escolar, Wahoo, Mahi mahi, Rainbow runner, and Opah.

Looking to the future, the development of an alia fleet[15], or future activity in the surface fishery, may result in the increased deployment of fish aggregation devices (FADs). Scientific research has shown that FADs can lead to an increase in the level of by-catch when fishing for tuna species.

Bailey et al. (1996) have conducted the most extensive review of bycatch in the Western and Central Pacific tuna fisheries based on log sheet data, observer information, and published and unpublished reports. Catch records available from log sheets for the period 1978-1992 ranged from nearly complete to seriously incomplete. Observer activity during this period was very low, so Bailey et al. also used information from increased observer activity in 1993 and 1994.

[13] http://www.fao.org/DOCREP/003/T4890E/T4890E00.htm#TOC
[14] http://www.spc.org.nc/OceanFish/Html/TEB/Bill&Bycatch/index.htm
[15] locally built aluminum catamarans

In the following sections we have summarized information on bycatch by gear, and bycatch by target species. The information in these sections comes primarily from Bailey et al. (1996), updated where possible.

3.2.1 Bycatch by gear

3.2.1.1 Purse seine fisheries

Data from SPC's Regional Tuna Fisheries Database (RTFD), from reports of observers' trips, from private logbooks, and from personal experience of the purse seine fishery in the WPO indicated an extremely low incidence of self-reported bycatch or of discards of bycatch and target catch (Bailey et al 1996). From 1975–1991, RTFD data showed that the total reported catch of this fishery exceeded 2.2 million mt, of which 0.21 per cent was listed as bycatch, 0.06 per cent as discarded bycatch and 0.24 per cent as tuna discards; for 1992, these values were 0.92 per cent, < 0.01 per cent and 0.3 per cent, respectively.

Poor reporting of bycatch and discards available from log sheet data and generally low observer coverage precluded definitive estimates of bycatch. However, observer-reported bycatch rates can provide some indication of bycatch levels in the WTP. For 1992, the bycatch level was determined, from observer data and ranges of CPUE by fleet, to be between 0.35 and 0.77 per cent of the total catch for school sets and between 3.0 and 7.3 per cent for log sets. Sets on floating objects produced the largest amounts, highest incidences and greatest variety of fish and other species, and accounted for more bycatch than school sets. The most common species in log sets, by frequency of occurrence, are the silky shark, mackerel scad, rainbow runner, mahi mahi and ocean triggerfish. However, Bailey et al. noted a trend for larger and more technologically advanced fleets to move away from log sets and concentrate on school fish. As the bycatch of school sets is less, bycatch levels may have decreased in more recent years.

Unlike the Eastern Tropical Pacific, evidence suggests that purse seine vessels in the western Pacific do not set on dolphins. Large baleen whales are occasionally set on in the WTP, but are easily able to escape alive and unharmed. Available data provide no evidence of seabirds taken in purse seines. Purse seines occasionally catch marine turtles but evidence suggests that the vessels release the majority of turtles alive. Marlin is uncommon in school sets, but relatively common in log sets. However, the overall catch is minor compared to the marlin catch of longliners operating in the same area. Purse seiners occasionally set on whale sharks in the WTP and reportedly injure these animals when attempting certain release techniques; no data on the magnitude of the injuries is available.

Purse seine vessels discard tuna irregularly and unpredictably, depending on setting practices of individual fishing masters, size of the catch, conditions during the set and condition of fishing gear. Considerable non-reporting of such discards for the investigation period makes estimates of discards impractical. However, three-quarters of reported tuna discards were made because the tuna were too small (< 3–4 lb or < 1.4–1.8 kg) for canning. Similarly, 76 per cent of reported tuna discards came from log and FAD sets.

The FAD fishing technique (sets on natural logs, anthropogenic flotsam, man-made FAD) has been introduced in different purse seine tuna fisheries for different reasons: to improve catch rates, minimize fishery expenses, to comply with "dolphin-safe" policy etc. Such fishing tactics may produce relatively high bycatch rates (Joseph, 1994; Bailey et al., 1996; Hall, 1996, 1998; Anon., 1997). Effort data from the U.S. purse seine fleet indicate an initiation of FAD fishing in 1995 (Figure 6). The number of sets on FADs increased substantially between 1998 and 1999 and dropped in 2000 as vessels tried to maximize catch value (by fishing on free swimming schools that tend to contain larger fish and higher proportions of yellowfin tuna) due to record low cannery prices for small tunas (<7.5 lb).

Aside from the problems of increase bycatch, Alverson *et al*. (1994) suggested that increased deployment of FADs and increased fishing on FADs could cause resource problems for tuna species. ICCAT has suggested that the introduction of FADs could have changed the behavior of skipjack schools and the migrations of this species in the eastern Altantic (ICCAT 2001). Prior to the use of those devices, the free schools of mixed species were much more common. Due to the large number of FADs, and the tendency of skipjack to associate with floating objects, substantial behavioral changes, including movement patterns, may occur. These behavioral changes may imply changes in the biological parameters of this species as a result of the changes in the availability of food, predation and fishing mortality. Skipjack caught with FADs are usually associated with small yellowfin (20%) and with small bigeye (17%) and also with other small tuna species. A comparison of size distributions of skipjack between periods prior to and after the introduction of FADs show, in the eastern Atlantic, an increase in the proportion of small fish in the catches and a decline in the total catch in recent years in some areas.

Bailey *et al*. noted that improvements to log sheet forms could make recording bycatch and discard data easier, although the problem of non-reporting of bycatch and discards will continue, as this type of information is provided on a voluntary basis. No form of enforcement would likely overcome these problems. Only a scientific observer program aimed at collecting accurate and representative data from all fleets involved would determine the true extent of the occurrence. An observer program would also provide necessary biological data such as species composition of the total catch.

3.2.1.2 Longline fisheries

As with the purse seines, under reporting and non-reporting generally prevented accurate estimates of bycatch and tuna discarding for the longline fleet (Bailey et al. 1996). The descriptions of billfish distribution, annual and seasonal catch rates by area, indications of size frequency by area and catch estimates appeared to be reasonable accurate on the log sheets. For the period 1978 to 1992, the RTFD contains a total WTP catch for the longline fishery of over 14,000,000 fish, of which 7 per cent was listed as bycatch, less than 0.1 per cent as discarded bycatch and less than 0.1 per cent as target tuna discards. However, available observer data give some indication of the likely levels of bycatch and discards.

As the estimated level of longline bycatch is highest, both in terms of the proportion of the total catch and weight of the catch, ecological concerns would most likely relate to longline bycatch. Historically, longline effort in the Pacific has changed little over the last 20 years, fluctuating between 450 and 600 million hooks (Figure 7) (Lewis 1999). Given some assumptions concerning stability of per-hook impacts over time, any ecological impacts of longlining on bycatch species are likely to be of long standing, and may be difficult to detect retrospectively (even if time series catch/effort data were available).

Australia and New Zealand have required releasing live billfish since the early 1980s, and data on survival rates of marlin taken by longline vessels suggested that releasing live billfish is a viable option, although there was some concern in regard to the enforcement of this requirement Bailey et al. 1996). Misidentification of billfish species appeared to occur in some WTP fleets, which would require additional work to ensure correct species identification on log sheets.

The catch of shark in the WPO constituted a large proportion of the total catch, but longline fisheries did not generally report shark catch on log sheets because it was not a part of the commercial catch. In spite of poor coverage, observer data provided a better indication of species breakdown. Blue shark *(P. glauc*a) appeared to be the most common shark species taken in the WPO longline fisheries, although oceanic white-tip and other *Carcharhinus* species were also prevalent in WTP catches. Australia has made some effort to increase the reporting of shark by providing a shark log sheet supplement for foreign fishing vessels, although the problems of misidentification of species and non- and under-reporting would reduce accuracy of log sheet data. Sharks have a high potential survival rates after release.

Limited observer data indicated little problem with longlines for bycatch of turtles, seabirds, or marine mammals. Incidental catches of skipjack and other non-target tuna species occurred throughout the WTP. Discarding of skipjack occurred variably between areas and fleets. Little was known about the exploitation levels of species other than billfish, shark and non-target tuna species. As in the purse-seine fishery, target tuna discards were an irregular and unpredictable feature of the longline fishery. The two major reasons for tuna discard were (i) small size and (ii) damage by sharks or marine mammals. Reporting of catch of the more commercially important species, such as wahoo and mahi mahi, could be improved by suitable changes in the format of catch log sheets. As with purse seines, only an observer program will obtain necessary biological data and provide information on non-reporting.

3.2.1.3 Pole and line fisheries

The pole and line fisheries depend on live bait that the vessels carry. Because the vessels target premium skipjack and have an incentive to conserve bait, tuna discard levels in the various pole-and-line fisheries in the WPO are likely relatively minor (Bailey et al. 1996). The RTFD indicated that bycatch from the pole-and-line fisheries in the WPO was less than one per cent, although the real level may be slightly higher, and likely varied with the type of school association. Bycatch levels were higher for pole-and-line fisheries based on FAD networks or in areas close to islands, reefs, or archipelagic waters than for high seas pole-and-line fisheries. A scientific observer program for the pole-and-line fisheries could provide more information on the bycatch levels and discard practices by fleet and school association. However, the small proportion of bycatch taken by commercial pole-and-line vessels and the substantial observer coverage needed suggest that observer effort would be best directed to the other more important fisheries of the WPO.

3.2.1.4 Troll fisheries

The troll fishery targets albacore primarily in the temperate waters around New Zealand or along the subtropical convergence zone (STCZ), in contrast to the tropical fisheries previously discussed (Bailey et al. 1996). Bycatch in the troll fishery was typically less than five per cent of the total catch on New Zealand grounds and less than one per cent in the STCZ. Much of the bycatch was taken to the north of the main fishing grounds as vessels moved to and from ports at the beginning and end of seasons and during unloading calls.

A total of 25 species of bycatch have been recorded in the fishery, including three species of shark, six species of scombrid, and two billfish species. Skipjack was the most common species on both grounds, often comprising over 70 per cent of bycatch. Most vessels discarded low market value bycatch species, but often retained more valuable species such as yellowfin tuna.

Troll gear generally caught only small billfish such as shortbill spearfish, as most escaped by breaking the troll gear. Seabirds often showed an interest in troll lures but the few caught were mostly released alive with little apparent damage. There were no records of marine reptiles or mammals being taken with troll gear.

Albacore weighing less than about 4 kg (57 cm) were often shaken off the hooks and returned to the sea alive. The limited information available on this deliberate ‘high grading’ of catch suggests that less than two per cent of a season’s catch were discarded because of size. The extent of the injuries suffered by the drop-offs and small discarded fish and their chances of survival are unknown. Negligible numbers of albacore were discarded because of shark damage.

A seasonal troll fishery for albacore, using identical gear and similar vessels to the South Pacific fishery, has existed in the North Pacific since the early 1900s. Although this fishery has been extensively researched and documented there appears to be no substantive literature on bycatch and discards. It appears from a NMFS observer programme that the fishery has a similar range of bycatch species to the South Pacific, including skipjack, yellowfin, shortbill spearfish, striped marlin, rainbow runner, and mahi mahi, and discarding of small albacore is known to occur.

3.2.1.5 Handline fisheries

Handline fisheries typically had less than one per cent of the total catch as bycatch (Bailey et al 1996). Shark species appeared to be the predominant bycatch discarded; due to the nature of this fishing method, the survival rate of any discarded bycatch is expected to be high. Seabirds, marine mammals or marine reptiles were not reported taken by handline fisheries in the WPO.

There is not enough information available to determine the level of tuna discards (due to poor quality) in the Coral Sea handline fishery, however, as there is some control on the rate of catch landed on deck (and hence the rate of subsequent processing/storage before deterioration), it is expected that this would be minimal. There are no quantitative data available on the level of tuna discards due to shark damage, although these are expected to occur from time to time. A scientific observer program for the handline fisheries could provide more information on the bycatch levels and discard practices. However, the small proportion of bycatch taken by commercial pole-and-line vessels and the substantial observer coverage needed suggest that observer effort would be best directed to the other more important fisheries of the WPO.

3.2.2 Bycatch by target species

Because of poor reporting of the catch of bycatch species on log sheets (which realistically is unlikely to improve, even in the long term), and the relatively low observer coverage, the total catch of the range of species can only be estimated, with considerable uncertainty surrounding existing estimates. Estimates do give an indication of the relative importance of bycatch and identify the species involved. The true catch rates of bycatch species over time is lacking, and the biology and population dynamics of nearly all species are poorly known such that impacts of fishing on bycatch species cannot presently be assessed (Williams 1997).

3.2.2.1 Sharks and rays

Compared to bony fishes, sharks are susceptible to overexploitation since they generally mature at a late age, have low fecunditites, long gestation periods, and are long lived (Graves et al 1999, Smith et al. 1998, Castro et al. 1999). Pelagic sharks and rays are a common bycatch of the WTP longline and purse seine fisheries, but very few data have been collected at the species level to enable insights into their distribution and abundance to the level that has been achieved for the target tuna species in the WTP. Observer data collection has provided a breakdown of elasmobranch species taken in these fisheries, with at least 16 species observed in the longline fishery and at least 10 species observed in the purse seine fishery.

Blue shark (*Prionace glauca*) is the most commonly caught species during commercial longline operations in the Pacific (Bigelowe et al. 1999). As many as 150,000 blue sharks are captured per year (Ito 1995), but the 1.6 blue shark per 1,000 hooks rate of catch (Figure 8) is significantly less than that reported in temperate longline fisheries (Williams 1997). For example, a catch rate of 10.4 blue shark per 1,000 hooks was calculated from data collected by observers monitoring vessels in the southern bluefin tuna *(Thunnus maccoyii*) fishery off the southeast coast of Australia (Stevens 1992). Catch rates from observer data suggest that, for the WTP longline fisheries, silky shark are taken at about half the rate of blue shark, and oceanic whitetip are taken at about one quarter the rate of the blue shark.

Blue shark are incidental by-catch and are often discarded after removal of their fins to satisfy increasing demand primarily from the Asian market. There has been a dramatic increase in the numbers of blue sharks finned by the Hawaii-based longline fishery; from 977 sharks in 1992 to 58,444 sharks in 1998 (McCoy and Ishihara, 1999). As a result, blue shark by-catch and finning practices have emerged as important fisheries management issues. Shark finning, and the commercial by-catch of sharks in general, are also coming under intense scrutiny by several non-governmental environmental organizations (NGOs).

Blue sharks are also probably the widest ranging shark species. They appear to make extensive and complex migrations, but movement patterns across seasons are not well documented. Because blue sharks are both ubiquitous and highly mobile, effective resource management, equitable resource allocations, and the population assessments upon which these are based, depend on a thorough understanding of long-term horizontal movement patterns. Data on movement patterns of pelagic fishes have traditionally been obtained either by analysis of catch statistics, tag and release studies, and direct observation of the movements of individuals carrying ultrasonic (usually depth sensitive) transmitters. Although all three methods can be effective, all have limitations in the quality of data that can be obtained (Musyl and Brill, abstract of current project under the Pelagic Fisheries Research Program: *Pop-Off Satellite Archival Tags to Chronicle the Survival and Movements of Blue Sharks Following Release from Longline Gear*,

The predominant shark species observed in the WTP purse seine fishery are the silky shark and the oceanic whitetip shark (Figure 9, Williams 1997). However, earlier observer work did not give priority to shark species identification and hence the shark species breakdown in the purse seine fishery is less clear than in the longline fishery at this stage. Nonetheless, it is apparent that only a very small percentage of the purse seine catch is made up of shark (around 0.15% by weight, according to observer data), which is a much lower rate per operation than for longline gear. The breakdown of shark species taken in the WTP purse seine fishery provides an interesting comparison with shark taken in the eastern Pacific Ocean (EPO) purse seine tuna fishery (Hall and Williams 1998). There are no observer reports of the blacktip shark *(Carcharhinus limbatu*s) in WTP purse seine fisheries, but this species is by far the most commonly encountered shark in the EPO purse seine fishery. The catch rate for sharks, in general, appear to be higher in the EPO than in the WTP purse seine fishery.

Observer accounts show that the fate of sharks and rays varies from fleet to fleet, from vessel to vessel within the same fleet, and may even vary within the same vessel trip (Williams 1997). The fate of sharks and rays taken in WTP longline fisheries is certainly more complicated that the common belief that all sharks have their fins removed and the trunks discarded. Certain species (e.g. pelagic stingray) have no economic value at all and hence are discarded whole. The fate of other shark species provides some insight into their economic value, with, for example, the trunk of the silky shark (retained in 45.8% of observed catches) apparently more valuable than the trunk of blue shark (retained in only 5.4% of observed catches). However, there have been reports that discarding practices may not be related to the species of shark taken and may change from day to day, for example, when storage space becomes critical towards the end of a trip. Williams (1997) reports that vessels retain sharks for consumption by the crew, and as food for live bait.

3.2.2.2 Billfish

Some billfish, notably swordfish and striped marlin, may be secondary or even primary target species in some longline fisheries (Lewis 1999). Target swordfish fisheries for example exist in Hawaii, Chile and more recently, eastern Australia, and most longline fisheries retain varying amounts of billfish for commercial sale, especially striped marlin. Black marlin and sailfish are more often discarded, but the degree of retention varies greatly amongst fleets. A recent OFP examination of longline billfish catches in the WCPO area (Williams and Bigelow, 1998) outlines some of the real difficulties in obtaining billfish estimates, but suggests that the 1995 catch for the four main species may have been of the order of 25,000t (44% swordfish, 26% blue marlin, 28% striped marlin and only 2% black marlin). Sailfish and spearfish were not included in the estimates. To this can now be added recent information on the Taiwan domestically based offshore longline fleet, which takes about another 7,000t of billfish (blue marlin 4,850t, swordfish 1,400t, sailfish 300t, black and striped marlin ~ 250t each). The WCPO billfish catch is now estimated as in excess of 32,000t.

3.2.2.3 Other fish species

The array of 40 or more fish species taken as bycatch in purse seine and longline fisheries (Lewis 1999) is diverse, and includes some of considerable commercial value and recreational fishing interest (e.g. wahoo, mahi mahi, opah,) or food value (e.g. rainbow runner, pomfret, mackerel scad, amberjack, escolar), whilst many others would seem to have little value in any context, other than components of the ecosystem (e.g. lancet fish, triggerfish). The catch and biology of nearly all these species, with exceptions of a few species such as mahi mahi, wahoo, is virtually unknown. The catch of mahi mahi by the Taiwan domestically based offshore longline fleet of over 6,500t p.a is noted.

3.2.2.4 Marine Turtles

Marine turtles are taken as bycatch in longline and purse seine fisheries in the WCPO. Bycatch in other fisheries such as pole and line and troll is considered to be non-existent. Incidental take of marine turtles is of particular concern due to their declining numbers and poor population status. All marine turtles are designated under the U.S. Endangered Species Act (ESA) as either threatened or endangered. The breeding populations of Mexico olive ridley turtles are currently listed as endangered, while all other ridley populations are listed as threatened. Leatherback turtles and hawksbill turtles are also classified as endangered. The loggerhead turtles and the green turtles are listed as threatened (note the green turtle is listed as threatened under the ESA throughout its Pacific range, except for the endangered population nesting on the Pacific coast of Mexico). These five species of marine turtle are highly migratory, or have a highly migratory phase in their life history, and therefore, are susceptible to being incidentally caught by fisheries operating in the Pacific Ocean.

In February of 2002, the Western Pacific Regional Fishery Management Council (U.S., NOAA) convened an international western Pacific forum to disseminate information and to promote greater regional collaboration for research and management of Pacific sea turtle populations[16].

According to Brogan (2002)[17], incidental catch in the longline fishery occurs when opportunistic-feeding marine turtles encounter baited longline hooks or when they are accidentally entangled with the longline gear. Turtle mortalities, when they occur, are directly related to entanglement or hooking with the longline gear and typically result from drowning. Marine turtles that are hooked or entangled not long before being hauled on board normally survive. Statistics on the life status of the marine turtle encounters varies by area and no conclusions can be drawn from the available data at this stage. Most of the turtles encountered by the Hawaii based longline fishery are released alive (see Appendix 1). Nevertheless, there is still a possibility that these turtles will die due to the interaction with the fishing gear. The U.S. Government uses a range of mortality probabilities, depending on the details of the interaction as recorded in the observer data (e.g. how the turtle was hooked, or entangled). Research is continuing in this area to refine estimates of post release mortality.

Observer-reported encounters clearly show that tropical areas have more turtle encounters. Of the various factors thought to affect the level of marine turtle encounters in the WTP longline fishery, the depth of set appears to be the most important. Analysis of available observer data suggests that the bait used, and whether the gear is set in the water during the day or night, does not have as marked an effect as do the strategies to set the longline gear shallow or deep.

Brogan (2002) provides a very preliminary estimate of 2,182 marine turtle encounters per year in the WTP longline fishery has been determined from available data, of which an estimated 500–600 are expected to result in mortality given the current level of awareness in this fishery. This estimate, however, is expected to have wide confidence intervals since observer coverage has

[16] http://www.wpcouncil.org/protected.htm
[17] http://www.wpcouncil.org/seaturtle/Pages%2072-114.pdf

been very low (<1%). Data on catches of turtles, marine mammals and seabirds for the Hawaii based longline fleet is provided in Appendix 1.

Brogan (2002) explains that marine turtle encounters in the purse seine fishery appear to be more prevalent in the western areas of the WTP. The main factor affecting marine turtle encounters in the WCPO purse seine fishery is set type. Animal associated, drifting log and anchored-FAD sets have the highest incidence of marine turtle encounters, compared to drifting FAD and sets on free-swimming schools (unassociated sets).

Brogan (2002) provides a very preliminary estimate of 105 marine turtle encounters per year in the WCPO purse seine fishery that has been determined from available data. It is expected that less than 20 of these encounters would result in mortality given the current level of awareness in this fishery. As with the WTP longline fishery, this estimate has wide confidence intervals since observer coverage is less than 5%.

Measures suggested by Brogan (2002) that have the potential to mitigate turtle bycatch and mortality include (i) the introduction and adoption by Pacific Island countries of a formal mechanism to advise all (longline and purse seine) fishing fleets of their responsibilities regarding the live discard of protected species, and (ii) the introduction of initiatives focussing on crew awareness and training in regards to reducing marine turtle mortalities.[18]

The U.S. government has taken substantially more stringent action to protect endangered and threatened turtle populations, including the total prohibition of longlining for swordfish north of the equator. Other restrictions apply to longline vessels targeting tunas. A complete list of restrictions on the U.S. based longliners is provided in Appendix 2.

3.2.2.5 Marine mammals

Endangered species of cetacean that have been observed in the Western Pacific include the humpback whale, sperm whale, blue whale, fin whale and sei whale. In addition, one endangered pinniped, the Hawaiian monk seal, occurs in the region.

There is little evidence that dolphin-associated sets are made by purse seiners in the SPC area (Lewis 1999). There a few records of pilot whales being encircled during log sets in some areas. Sei whale and whale shark (not a mammal) sets are more common in equatorial areas, but these very large animals are usually released unharmed. Marine mammals may occasionally be entangled in longline gear, but there appear to be few examples of actual hooking by longline gear. False killer whales and pilot whales, on the other hand, are seen as serious pests, as they systematically strip target tuna from the longlines, but are rarely if ever caught.

3.2.2.6 Seabirds

According to Lewis (1999), unlike the situation in more temperate areas, catches of seabirds by longline gear are rare in the tropical and sub-tropical areas of the WCPO. This is mainly because the bird species most commonly involved in interactions with longlines in temperate areas (e.g. albatross, petrels) are rare or absent from tropical areas. However, the Hawai'i-based longline fishery results in the annual mortality of thousands of protected black-footed and Laysan albatross that nest on the Northwestern Hawaiian Islands[19]. Seabirds follow longline vessels and dive on the baited hooks, become hooked and subsequently drown. It is estimated that between 1994 and 1999, an average of 1,330 Laysan albatross *Phoebastria immutabilis* and 1,743 black-footed albatross *Phoebastria nigripes* were killed in the Hawai'i-based longline fishery each year.

[18] See for example the US Guidelines for handling hooked sea turtles at http://swr.ucsd.edu/piao/ghhst.htm
[19] Final Environmental Impact Statement, Pelagic Fisheries of the Western Pacific Region, NOAA Fisheries, Dept. of Commerce, U.S. Government. http://swr.ucsd.edu/piao/eisdocs.htm

The average annual incidental catches of black-footed and Laysan albatross in the Hawai'i longline fishery (based upon NMFS statistical analysis) represent about 0.45 and 0.06 percent of the total estimated populations of these species, respectively. Data collected by US observers show that when Hawai'i-based longline vessels target swordfish the incidental catch of seabirds (0.758 bird catch/set) is far higher than when vessels target tuna (0.013 bird catch/set). One reason for this difference in catch rates is that vessels targeting swordfish are more likely to operate within the foraging range of the seabirds. The region of greatest interactions between seabirds and the Hawai'i-based longline fleet is a latitudinal band from 25º N. to 40º N., from the dateline to about 150º W. longitude. Table 1 provides some examples of techniques that may help to reduce interactions with seabirds on longline vessels.

Overall estimates of the effectiveness of mitigation measures in reducing the incidental catch of seabirds in the Hawai'i-based longline fishery were computed by averaging the impacts on seabird interactions determined by research and US longline observer estimates (Hawaii Longline Fishery EIS). Some methods appear to have gret potential to significantly reduce the incidental catch of albatross in the Hawai'i-based longline fishery but no one measure is likely to be totally effective by itself. Combining two or more measures is expected to improve overall mitigation effectiveness.

There are no records of bird catches by purse seiners in the WCPO (Lewis 1999).

Table 1. Discussion of Seabird Mitigation Measures Evaluated for the Hawai'i-based Longline Fishery. Source: Page 2-61 of the Final Environmental Impact Statement, Pelagic Fisheries of the Western Pacific Region, NOAA Fisheries, Dept. of Commerce, U.S. Government. BF= black-footed albatross *Phoebastria nigripes;* LA = Laysan albatross *Phoebastria immutabilis.*

Mitigation Measure	**Discussion**	**Percent reduction in Incidental Catch**
A. Discharge offal strategically:	While gear is being set or hauled, fish, fish parts or bait should be strategically discharged on the opposite side of the vessel from which the longline is being set or hauled. This mitigation method requires the preparation and storage of hook-free offal for strategic use during the longline set. The intent of this measure is to divert seabirds from baited hooks to other food sources when necessary to reduce interactions.	BF 83 LA 91
B. Night setting:	The longline set should begin at least one hour after sunset and be completed at least one hour before sunrise. The purpose of setting fishing gear during hours of darkness is to reduce the visibility to seabirds of baited hooks at the water's surface. If branch lines are weighted, light sticks should not significantly reduce the sink rate. The effectiveness of this deterrent may be reduced by deck lighting, which is necessary for crew and vessel safety.	BF 95 LA 40
C. Blue-dyed and thawed bait:	An adequate quantity of blue dye should be maintained on board, and only bait dyed a color that conforms to Council/NMFS standards may be used. All bait should be completely thawed before it can be dyed. The objective of dyeing bait blue is to reduce the visibility to seabirds of baited hooks at the water's surface. In addition, completely thawed bait tends to sink faster than frozen bait during the longline set, thereby reducing the time that baited hooks are accessible to seabirds.	BF 95 LA 90
D. Towed deterrent:	A line with suspended streamers (tori line) or a buoy that conforms to Council/NMFS standards must be deployed when the longline is being set and hauled. These devices scare seabirds from baited hooks at the water's surface as well as provide a physical barrier that reduces the ability of seabirds to approach the hooks. This deterrent presents a risk of fouling with longline gear as it is being set and it increases the danger to crews and vessels during setting and hauling of gear.	BF 86 LA 71
E. Weighted branch lines:	At least 45 g of weight should be attached to branch lines within one meter of each baited hook. The purpose of attaching weights to branch lines is to increase the sink rate of baited hooks, thereby reducing the availability of baited hooks to seabirds.	BF 93 LA 91
F. Line-setting machine with weighted branch lines:	The longline should be set with a line-setting machine (line-shooter) so that the longline is set faster than the vessel's speed. In addition, weights of at least 45 g must be attached to branch lines within one meter of each baited hook. Using wire leader enhances the weight of the branch line. The purpose of this measure is to remove line tension during the set, thereby increasing the mainline sink rate and reducing the time that baited hooks are at the surface and accessible to seabirds.	BF 98 LA 97

On May 14, 2002, NMFS published a final rule requiring that[20]:

- Hawaii-based vessels operating with longline gear north of 23E N., are required to use thawed blue-dyed bait and strategic offal discards to distract birds during setting and hauling of longline gear.
- When making deep sets (targeting tuna) north of 23E N., Hawaii-based vessel operators are required to employ a line setting machine with weighted branch lines (minimum weight = 45 g), or use basket-style longline gear deployed slack.
- Hawaii-based longline vessel owners and operators are required to follow prescribed handling techniques so that seabirds brought onboard alive are released in a manner that maximizes the probability of their long-term survival.
- Hawaii-based vessel owners and operators must annually complete a protected species educational workshop conducted by NMFS.

3.3 Foodweb effects

Adult tunas and billfish are at the apex of pelagic food webs in the WCPO (Figure 10). Much of the concern regarding the effects of fishing on marine food webs stems from targeting on species lower down in the hierarchy, and particularly prey or forage species on which higher level predators rely, rather than species in the upper levels. IATTC (2001), for example, states that fisheries impart top-down influence on some apex predators in the tropical EPO, but the effects of fishing did not propagate down to the forage species at the middle trophic levels. Bottom-up processes, however, appear to affect the entire food web. The longevity of the system's components and the temporal scales at which variability is transmitted up the food web appear to be important in structuring pelagic food webs.

However, Kitchell et al. 1999 have pointed to a growing body of evidence that changes at the tops of food webs are expressed at all trophic levels in a wide variety of aquatic ecosystems. Kitchell et al. used an Ecopath simulation model to investigate whether one or more members of the apex predator guild in the Central Pacific might be regarded as a keystone predator [21]. The model showed that adult yellowfin and skipjack tunas have critical roles in the food web. Their removal evoked substantial and sustained changes to the structure of the system. In addition to being important and abundant consumers, they are among prey items for higher order predators such as billfishes and sharks. More work needs to be done to better understand how the effects of removal of higher predators propagate through the food web, but it is clear that the status of these apex predators and their ecological significance can only be known through monitoring of fisheries and diet composition.

3.4 Biodiversity

The Convention on Biological Diversity concluded at the UN Conference on Environment and Development in Rio 1992 defines biodiversity as:

> *"The variability among living organisms from all sources including,* inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species and of ecosystems."*

This broad definition can be interpreted in many ways. Conventionally, biodiversity is considered at three levels: ecosystem, species, and genetic diversity (Norse 1993, Norse *et al.*

[20] http://swr.ucsd.edu/piao/eis/rod.htm
[21] One whose impact on its community or ecosystem is large, and disproportionately large relative to its abundance (Power et al. 1996).

1986). Whilst perhaps representing the most basic level of biological diversity, genetic diversity, encompassing the variation amongst individuals, is the least visible and least studied. By contrast, species diversity, commonly expressed in terms of numbers of species, is the most obvious level, and the level that is most often referred to in the common usage of the term "biodiversity." Definitions of ecosystem diversity take into account a given biological community of organisms and the area in which they live. For example, habitat diversity is the most frequently used quantitative measure of biodiversity because habitat can be defined relatively clearly in terms of both physical conditions and biotic components.

There are several general patterns of diversity that have been observed within the marine environment. Characteristically, there is a latitudinal gradient of species diversity between the poles and the tropics. There is a general cline of increasing diversity towards the tropics, although this is less well defined in the southern than in the northern hemisphere (Kendall and Aschan 1993). There is also a gradient between inshore and offshore areas. As a general rule, waters that overlay continental shelves contain more diverse communities than those of the open ocean. Patterns have also been observed in substrate types. For example, in soft sediments, diversity increases from shallow areas to deep waters (Grassle and Maciolek 1993).

Currently, there are no quantitative community-based models that link the activities of fishing fleets to biodiversity. It is, however, possible to identify the types of processes within industrial/commercial fisheries that impact on communities of organisms and habitat biodiversity.

Trophic systems such as that illustrated in Figure 10 represent a starting point for evaluating possible effects of fisheries on biodiversity at the ecosystem level. Trophic studies based on analysis of stomach contents indicate the importance of key commercial species, both as prey and predators. Data of this type indicate areas of potential conflict between the demands made by the fisheries sector and the need for conservation of overall biodiversity.

Loss and/or degradation of habitat is currently recognised as the most critical threat to marine biodiversity (Heywood and Watson 1995); prevention of such loss or degradation is considered to be the most effective way of conserving biodiversity. Other than direct modification of population sizes and the relative composition of species assemblages, as noted elsewhere in this document, there are not considered to be any substantive direct effects of pelagic tuna fisheries in the WCPO on marine habitats. A possible exception to this is the effects of anchoring of FADs, which may have some local impact that should be evaluated prior to installation and monitored subsequently.

3.5 Environmental effects on productivity

Tuna distribution and abundance have been shown to be sensitive to environmental variability (OFP[22]). In particular, the El Niño Southern Oscillation (ENSO) appears to have important consequences both for spatial distributions and migrations of the tuna populations and for their level of recruitment and biomass. Interestingly, the signal appears to be opposite according to the species, e.g., an El Niño event would have a positive influence on the recruitment of skipjack while the effect would be negative on the albacore. In addition, the interannual signal presents a correlation with the Pacific Decadal Oscillation (PDO), leading to two different regimes characterized by higher intensity and frequency of either El Niño or La Niña events.

Exceptionally high catches of skipjack between 1998 and 2000, were linked directly to strong recruitment related to the powerful 1997-98 El Niño event. It is also expected that the La Niña sequence of 1999-2001 has negatively affected the recruitment of skipjack and should lead to lower biomass in 2002-2003 (GLOBEC Newsletter October 2002). Similar trends occur for yellowfin tuna, the second tuna species by volume of capture. However, a longer life span for this species produces lower-frequency fluctuation in the population biomass. The most recent

[22] http://www.spc.org.nc/OceanFish/Html/TEB/Env&Mod/index.htm

population assessments of yellowfin tuna show that lower recruitment in the recent years have produced a significant decline of around one third in overall stock biomass since 1997 (Hampton 2002), suggesting a possible shift to a lower productivity regime. Biomass levels in 2000 and 2001 are estimated to be the lowest since the mid-1970s. If a shift to a lower productivity regime is confirmed, it is believed that present catches may not be sustainable.

Work in the EPO reported in ICCAT (2001) has demonstrated that applying realistic physical forcing to a complex ecosystem model has provided insight into the behavior of the ecosystem and the effects of bottom-up processes on the middle and upper trophic levels. Frequent ENSO events were predicted to increase the transfer efficiency of energy from the producers to animals occupying middle trophic levels, with an opposite but lesser effect on the apex predators.

4 Recommendations

There are two general situations in which managers may find themselves when striving to better account for ecosystem effects of fishing. Firstly, explicit management measures may be established in advance in order to mitigate potential likely adverse ecosystem effects of fishing (preventive action). Secondly, and more commonly, management action may be required to promote recovery from adverse impacts that have already occurred, but either were not considered when the FMP was formulated, or were not thought to be likely outcomes of the activity sanctioned under the FMP (corrective action).

It is clearly more desirable to establish measures that avoid adverse impacts before they take place. However, this is often problematic, in part because there is usually very little information available prior to the onset of fishing and the chances of making correct decisions the first time is often low. Corrective action allows uncertain processes to unfold, with a plan that unintended consequences will be mitigated if and when they occur. This allows trial-and-error types of decision making in an adaptive framework. However, fisheries often develop faster than the acquisition of data necessary to ensure that management can address mitigation of adverse impacts. A fisheries development framework such as that being elaborated by CCAMLR is a useful tool in such situations. This framework incorporates a number of regulatory requirements including advance notification of intent to participate in a fishery, research and fishery operations plans and data collection plans for all fisheries commensurate with their current status. When either uncertainty and/or the potential cost of errors are more than low, it becomes necessary to adopt a precautionary approach.

Enhanced and directed monitoring is an essential element of an ecosystem approach that seeks to take into consideration unintentional, secondary and/or indirect effects of fishing on target species with particular fishing gears. A major feature of this monitoring is likely to be increased use of observers[23], which is perhaps the only means currently available of obtaining independent information on catch and bycatch statistics at the species level, while also providing vessel and fishing effort information. Modelling is also required not only to develop a better understanding of ecological relationships and ecosystem effects, but also to explore in advance the effects of different management alternatives and their monitoring requirements.

The evaluation of management procedures by extensive computer simulation prior to their implementation provides the opportunity to eliminate management options that would fail to meet the objectives, thereby potentially avoiding a trial and error approach that has led to various kinds of problems. Methods for the elaboration of new fisheries and for managing existing fisheries while introducing a precautionary approach that accounts for uncertainty have been developed by CCAMLR (Constable *et al.* 2000) and the FAO (FAO 1995). Prospective evaluation via simulation in a staged approach allows for the implementation of a management procedure that is most likely to achieve the objectives despite uncertainties in the various parts of the system, including the limitations of a monitoring program, such as incomplete data and low power in assessments. It can also be used to ensure that the costs of management are commensurate with the value of the fishery. Prospective evaluation of management procedures is especially important if one wants to conduct adaptive management, in which harvest rules are set to produce both fish and information that allows one to reduce uncertainty.

Fishery managers need the following components of a fisheries management strategy as soon as possible:

[23] Currently there are active observer programmes in the Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Papua New Guinea and Solomon Islands. These countries are soon to be joined by French Polynesia and New Caledonia who have recently secured PROC FISH (EU) funds. http://www.spc.org.nc/OceanFish/Html/TEB/Bill&Bycatch/index.htm

- a conceptual framework for considering ecosystem issues and the variety of factors that may influence the dynamics of higher level predators, including the development of reference points for states of nature akin to those used in more conventional fisheries stock assessment;

- models that can be used to explore the effects of alternative approaches to fisheries management on endangered species, such as marine turtles and birds; and

- a framework for establishing a monitoring program that could be set in place to assist managers in making decisions about the effects of fishing on the ecosystem.

Both data and models need to be specific to particular situations, designed to inform managers and the public about characteristics of the ecological system that are of interest to them. Such ecological attributes need to be summarized in a collection of ecological indicators, which are quantities that can be computed from the data and which provide information about the status of the ecological attributes. Examples of such indicators include

- Biomass / stock size
- Total mortality (catch divided by a catch limit)
- Size / age-structure
- Catch-rate
- Discard rate
- Size-spectra (using log size-classes)a
- k-dominance curves
- Coefficient of variance for total biomass
- Average trophic level
- Diversity index (e.g. Reyni or Shannon-Weiner)
- Species composition (MDS plots)
- Rate of damage
- Benthic habitat complexity
- Biomass of cover-defining species / species groups
- Reproductive success
- Ratios of piscivores : planktivores and / or demersal fishes
- Chlorophyll-a
- Redfield ratio
- Throughput
- Production / biomass
- System ominvory index
- Dominance of detritus
- Relative ascendancy
- Residence time (= biomass/(respiration+export))
- Index of Biological Integrity (IBI)

Murawski (2000) provides an important contribution in the quest for operational indices of ecosystem condition by considering the quantitative basis for defining what he terms “ecosystem overfishing”. He points out that there is no specific ecosystem analogue to single-species definitions of overfishing – no single utilitarian metric of ecosystem condition, and hence ecosystem overfishing. However, he proposes the development of explicit ecosystem overfishing criteria that may be used to establish multiple tiers of measures to address issues inadequately covered by conventional single species oriented management. He concludes that ecosystems can be considered to be overfished when cumulative impacts of catches (including discards), non-harvest mortality and habitat degradation result in one or more of the following conditions:

- Biomasses of one or more important species assemblages or components fall below minimum biologically acceptable limits, such that (1) recruitment prospects are significantly impaired, (2) rebuilding times to levels allowing catches near MSY are extended, (3) prospects for recovery are jeopardized because of species interactions, or (4) any species is threatened with local or biological extinction;

- Diversity of communities or populations declines significantly as a result of sequential "fishing-down" of stocks, selective harvesting of ecosystem components, or other factors associated with harvest rates or species selection;

- The pattern of species selection and harvest rates leads to greater year-to-year variation in populations or catches than would result from lower cumulative harvest rates;

- Changes in species composition or population demographics as a result of fishing significantly decrease the resilience or resistance of the ecosystem to perturbations arising from non-biological factors;

- The pattern of harvest rates among interacting species results in lower cumulative net economic or social benefits than would result from a less intense overall fishing pattern or alternative species selection;

- Harvests of prey species or direct mortalities resulting from fishing operations impair the long-term viability of ecologically important, non-resource species (e.g. marine mammals, turtles, seabirds).

These conditions could therefore be regarded as a selection of metrics of ecosystem status that provide the basis of thresholds that should be avoided in an attempt to prevent ecosystems from becoming "unhealthy". What is perhaps harder to do is fulfill the need for management targets that can be aimed at, in the sense of restoration and maintenance of ecosystem function, as opposed to thresholds that should be avoided.

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6 Figures

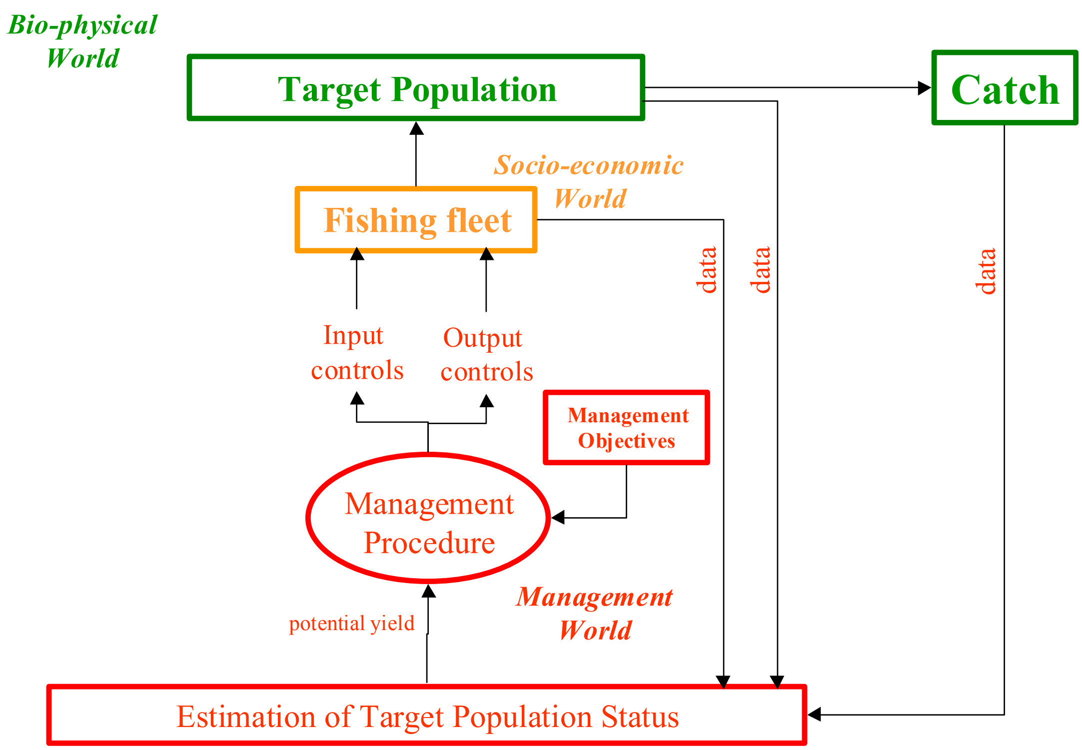


Figure 1 The conventional assessment world view, in which nearly all fishery management is currently done, recognizes the biophysical world in which the stock exists, the socio-economic world of the fishing community that takes the stock, and the management world in which catch limits are determined.

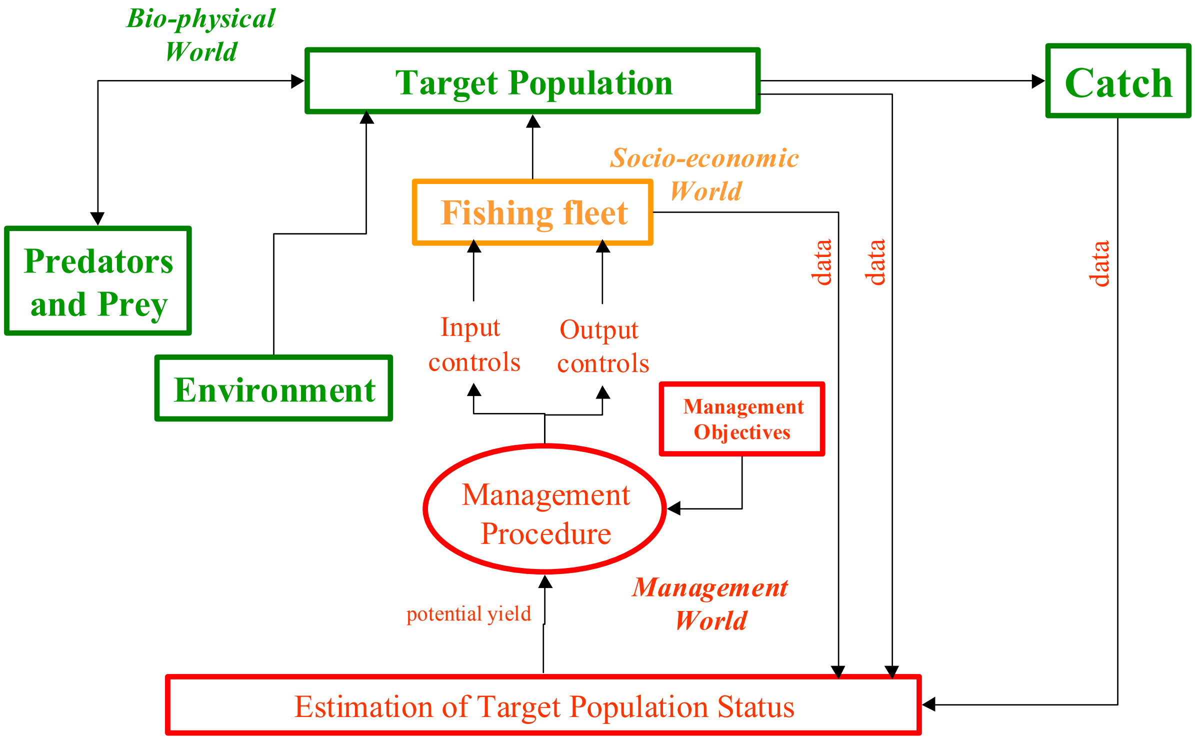


Figure 2 In the implicit ecosystem effects world view, we recognize that target species in fisheries are generally prey for other components of the ecosystem. While management objectives only take such predator needs into account in a very general way, the implicit view is cognizant of those needs.

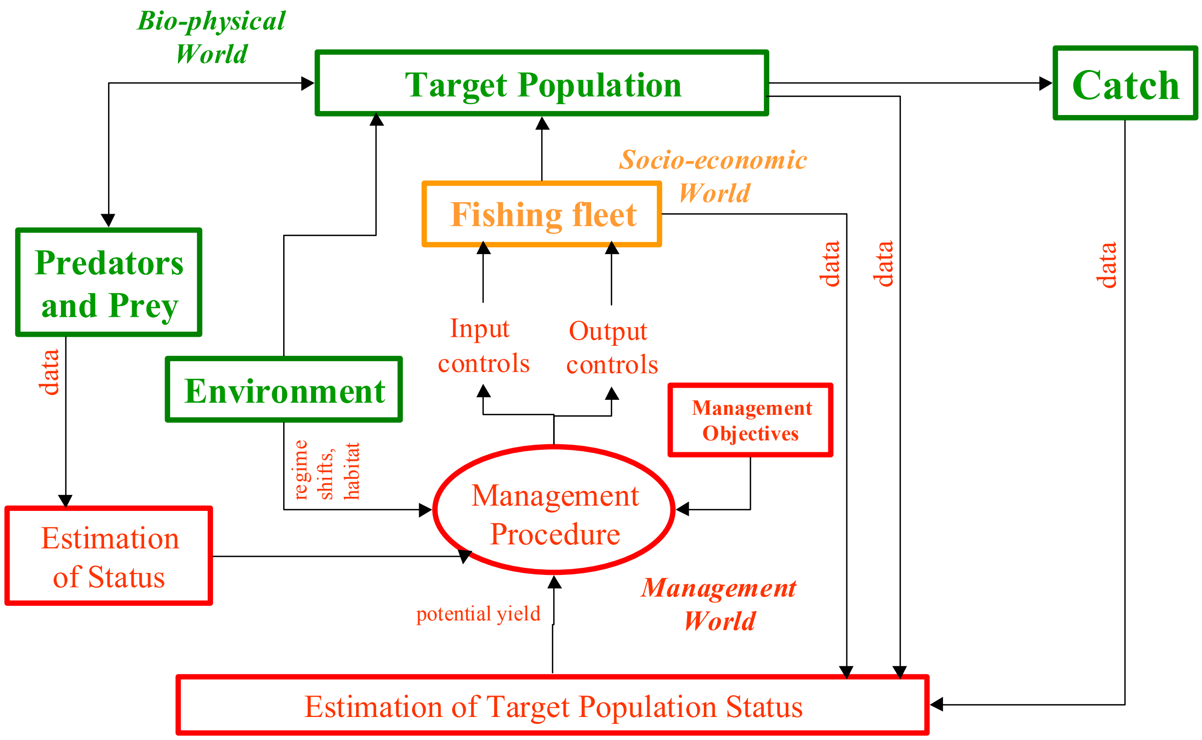


Figure 3 In the first stage of management that takes ecological and ecosystem considerations into account in an explicit manner, both the status of the target stock and its predators and prey are considered, but these are not integrated in a holistic management plan. In some sense, then status of prey and predators thus constrain the catch limit from the management procedure.

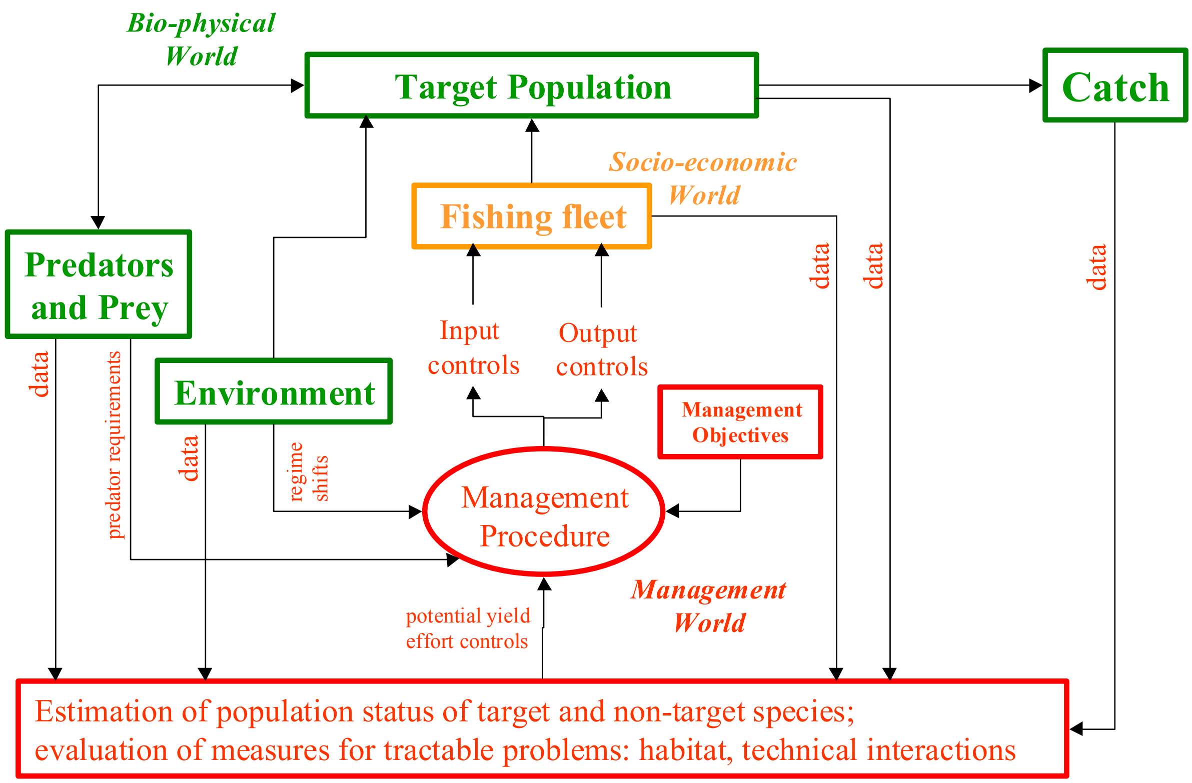


Figure 4 In the second stage of explicit consideration of ecological and ecosystem effects, one takes into account environmental effects in a more direct fashion in consideration of the status of the target stock and incorporates measures for more tractable problems.

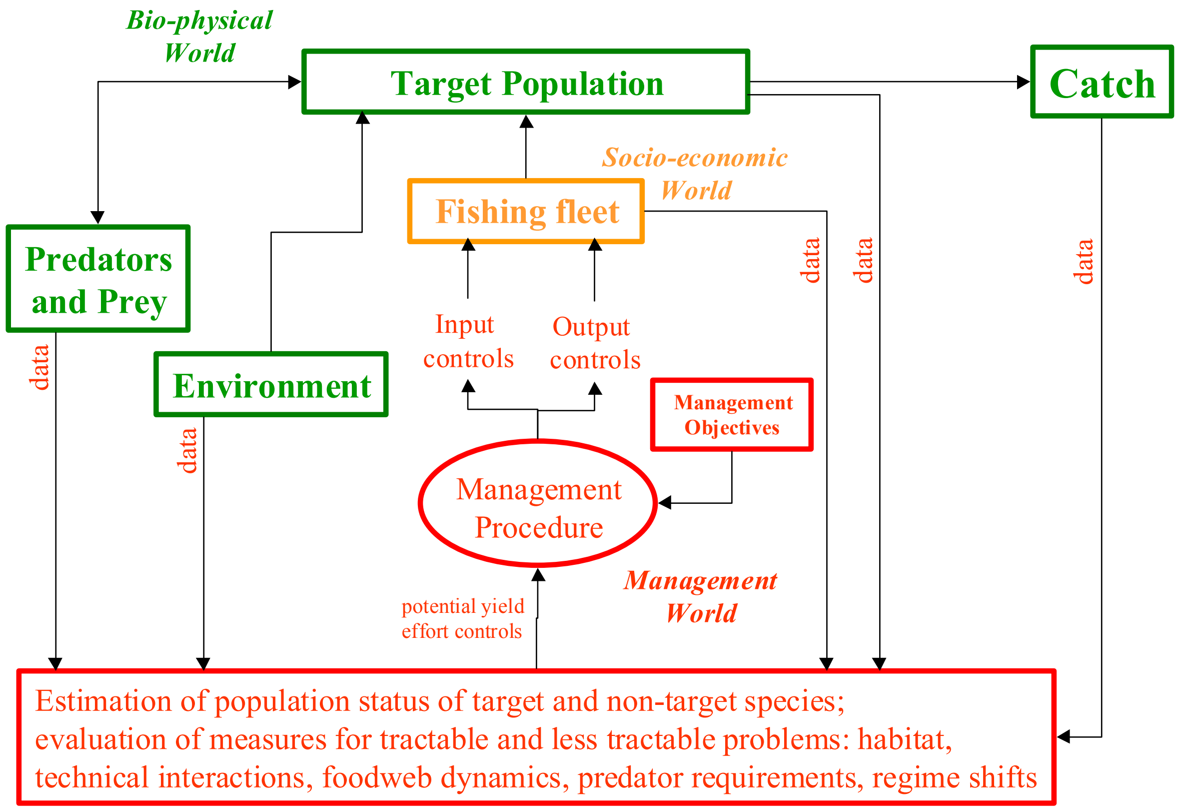


Figure 5 In the third stage, the environment, target stock, and its predators and prey are integrated in the assessment before the management procedure is used to determine catch limits. At the same time, less tractable problems are included.

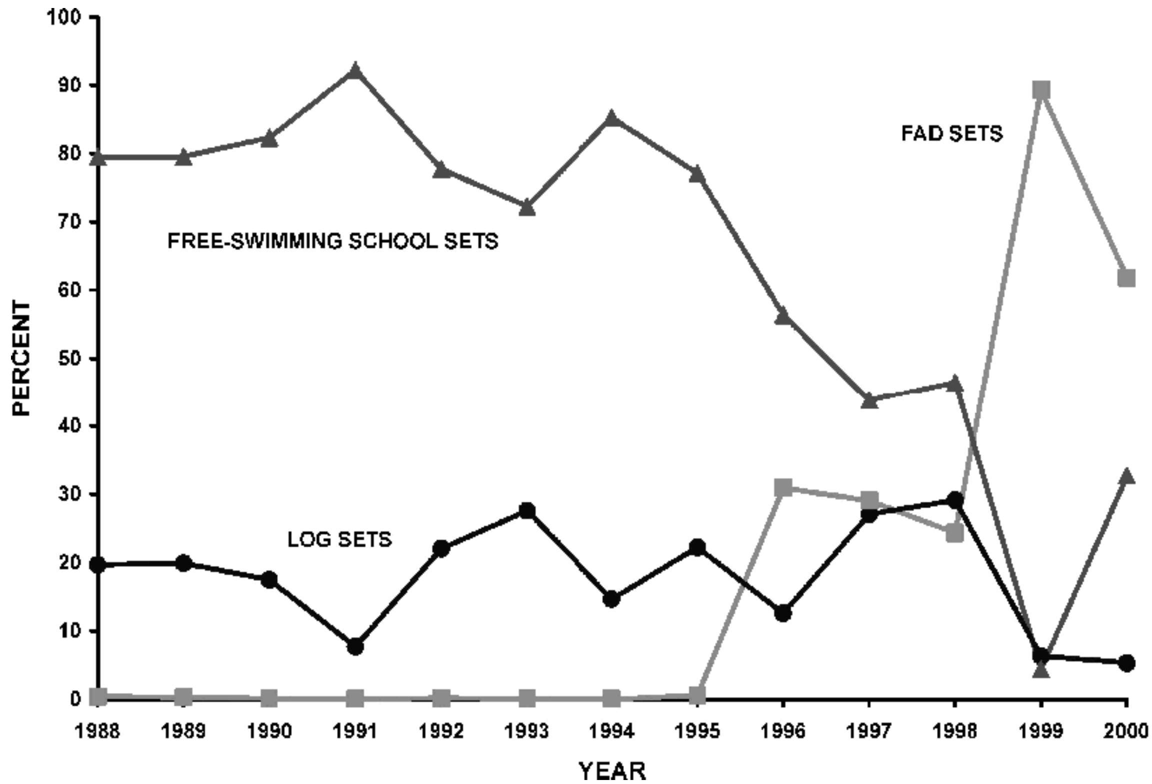


Figure 6. Changes in Purse seine sets by the US Purse Seine Fleet, 1988 to 2000 (NMFS 2001)

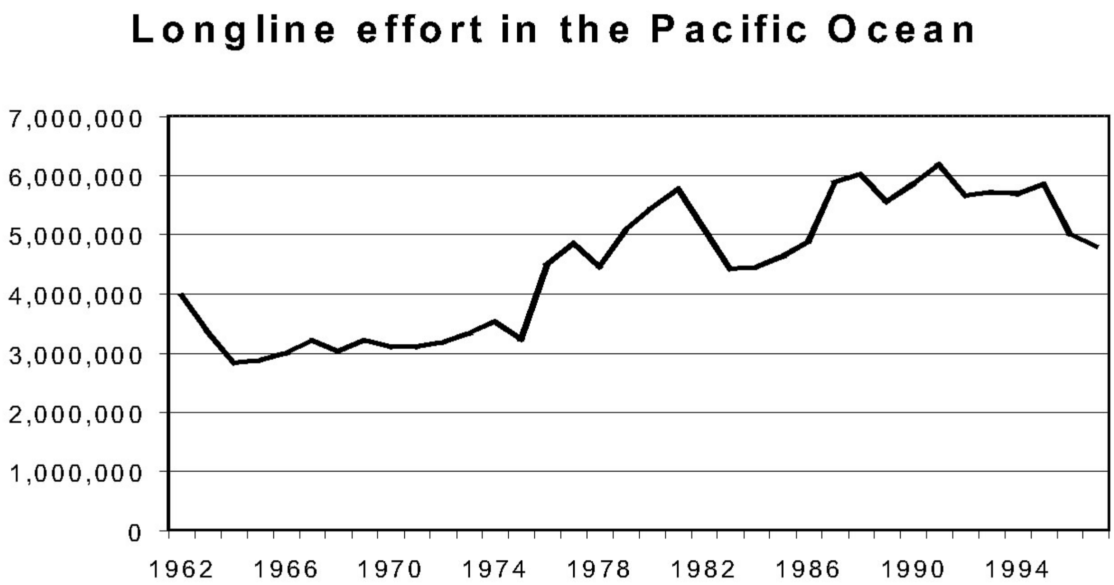
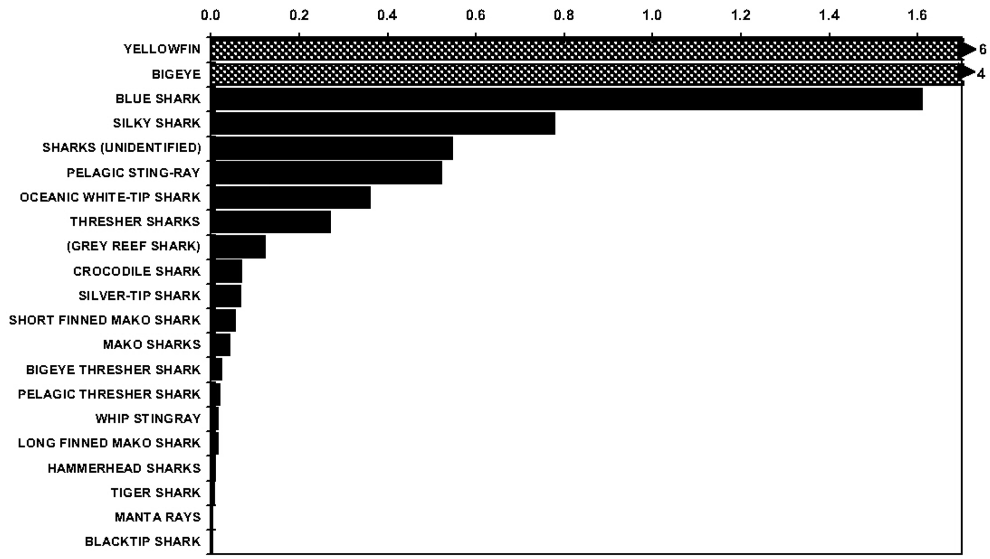


Figure 7. Historical longline effort in the Pacific Ocean (units are 00's of hooks) (after Lewis 1999)

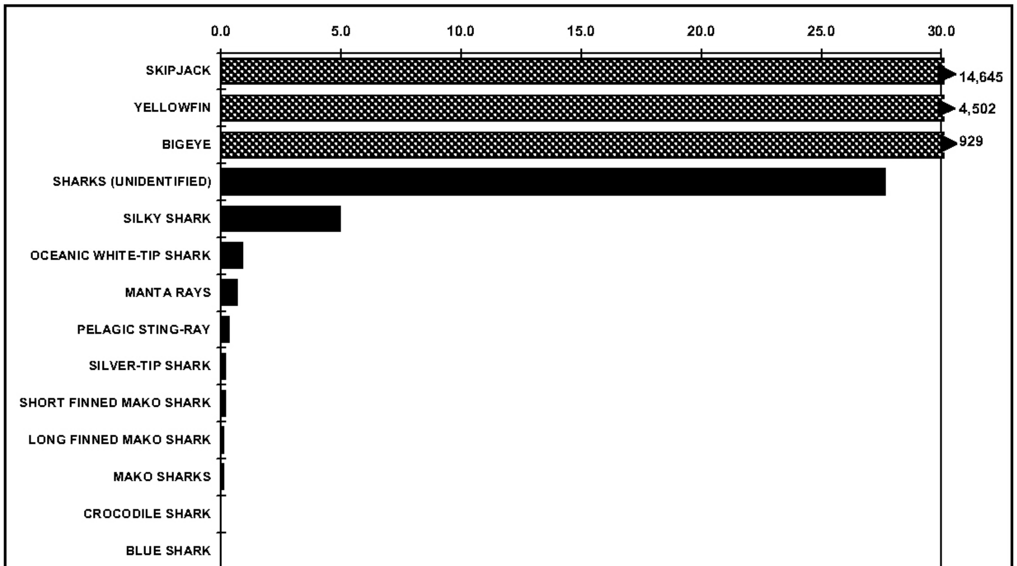


Nominal catch rates (fish per 1,000 hooks) of sharks and rays taken in the WTP longline fishery based on available observer data (1993–1997).

Notes

1. Nominal catch rates of target tuna species have been included;
2. Sharks and rays observed but not identified to the genus or species level have been included;
3. The coverage of observer data is less than 1% of longline activity in the WTP.
4. The observations of the grey reef shark (*C. amblyrhynchos*) are believed to be misidentification of the silky shark (*C. falciformis*) in most cases, but are yet to be confirmed.

Figure 8 (after Williams 1997)



Nominal catch rates (kg of fish per set) of sharks and rays taken in the WTP purse seine fishery based on available observer data (1994–1997).

Notes

1. Nominal catch rates of target tuna species have been included;
2. Sharks and rays observed but not identified to the genus or species level have been included;
3. The coverage of observer data is considered to be less than 3% of overall purse seine activity.

Figure 9 (after Williams 1997)

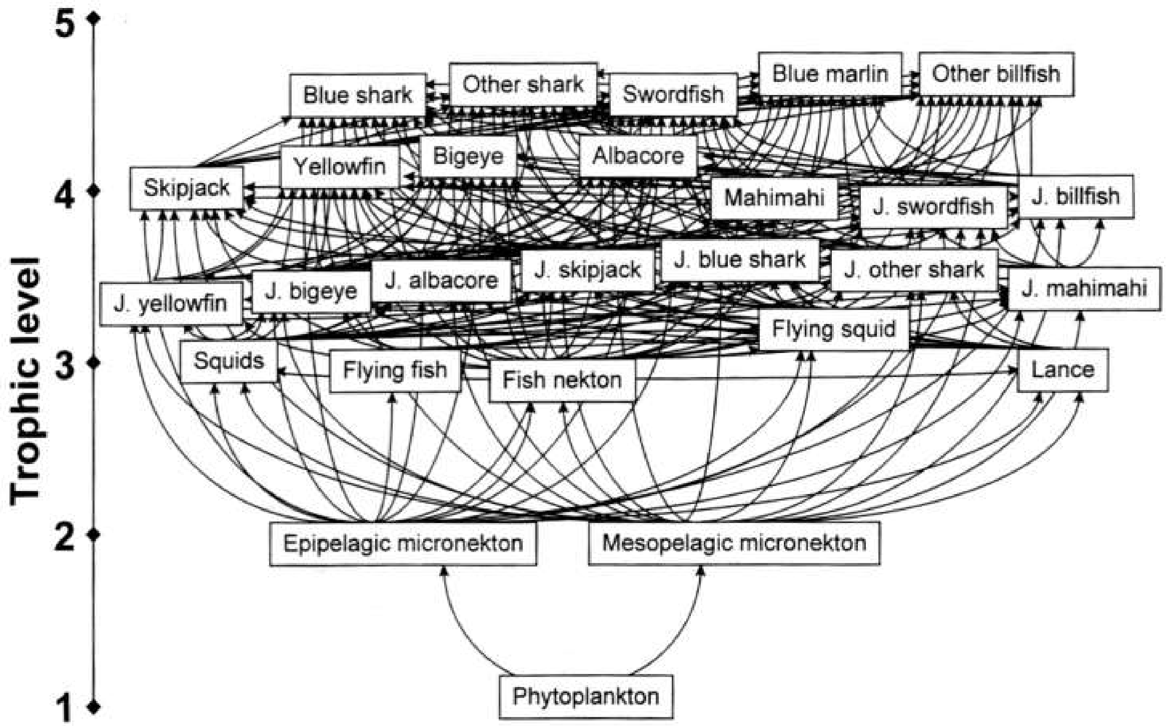


Figure 10. A food web diagram of the Ecopath model for the central Pacific (after Kitchell et al. 1999)

Appendix 1. Bycatch of turtles, marine mammals and seabirds in the Hawaii Longline fishery

Data on observed encounters with turtles, marine mammals and seabirds between 1994 and 2000. NA = data not available. Extracted from Hawaii Longline Observer Program[24] annual reports, Fisheries Observer Branch Southwest Region, National Marine Fisheries Service, U.S. Government.

	Period						
	Feb 24 1994 to Feb 20 1995	Feb 21 to Dec 31 1995	1996	1997	1998	1999	2000
Total Sets observed	570	488	624	507	561	463	1401
Total Hooks Set	599,700	543,248	731,687	585,763	734,204	687,703	2,238,842
Observed Trips*	55	42	52	38	47	38	109
Trips without Turtles	36	31	30	20	21	24	81
Trips with Turtles	19	11	22	18	26	14	28
Turtle Encounters	38	18	50	40	60	30	54
Released Alive							
Loggerhead	20	10	26	24	45	17	27
Leatherback	8	3	7	11	5	1	11
Olive Ridley	4	2	8	3	2	6	8
Green/Black	2	0	3	0	2	2	3
Unid. Hardshell	3	2	2	0	0	1	0
Returned Dead							
Loggerhead	0	0	0	0	1	0	0
Leatherback	0	0	1	0	1	1	0
Olive Ridley	0	1	1	0	3	1	3
Green/Black	0	0	0	0	0	1	2
Released, Disposition Unknown							
Loggerhead	0	0	1	0	0	0	0
Leatherback	1	0	1	1	0	0	0
Unid. Hardshell	0	0	0	1	1	0	0
Turtles per 1,000 hooks	0.063	0.033	0.063	0.068	0.082	0.044	0.024
Marine Mammal Encounters	NA	3	3	5	3	5	8
Released Alive							
False Killer Whale	NA	0	0	1	1	0	0
Risso's Dolphin	NA	2	1	2	0	2	1
Spinner Dolphin	NA	0	0	1	0	0	1
Bottlenose Dolphin	NA	1	0	0	0	1	0
Common Dolphin	NA	0	0	0	0	0	1
Sperm Whale	NA	0	0	0	0	1	0
Short-Finned Pilot Whale	NA	0	0	0	0	0	1
Unid. Whale	NA	0	1	0	2	1	1
Unid. Cetacean	NA	0	0	0	0	0	2
Returned Dead							

[24] http://swr.ucsd.edu/hcd/hillobs.htm

	Period						
	Feb 24 1994 to Feb 20 1995	Feb 21 to Dec 31 1995	1996	1997	1998	1999	2000
Short-Finned Pilot Whale	NA	0	0	1	0	0	1
Released, Disposition Unknown							
Unid. Cetacean	NA	0	1	0	0	0	0
Seabird Encounters	205	208	90	172	104	71	248
Released Alive							
Black-footed Albatross	24	22	13	24	6	7	29
Laysan Albatross	32	28	6	19	26	7	30
Unid. Seabird	0	0	0	0	1	0	0
Returned Dead							
Black Footed Albatross	106	79	46	86	39	36	133
Laysan Albatross	42	78	25	43	30	21	55
Sooty Shearwater	0	0	0	0	0	0	1
Unid. Seabird	1	1	0	0	0	0	0
Released, Disposition Unknown							
Black Footed Albatross	0	0	0	0	1	0	0
Laysan Albatross	0	0	0	0	1	0	0

* The number of observed trips in this table refers to the number of completed trips (i.e. those with returning observers) within the relevant period.

Appendix 2. U.S. Sea Turtle Conservation Measures applying to longline fisheries in the Western Pacific Region

FISHERY MANAGEMENT PLAN
PELAGIC FISHERIES OF THE WESTERN PACIFIC REGION

Current as of September 2002[25]:

- Operators of all U.S. longline vessels permitted under the Pelagics FMP (including vessels based in American Samoa, Guam, and the CNMI are prohibited from using longline gear to target swordfish north of the equator. To accomplish this, NMFS has decided to issue rules to require that:

    - Operators of all U.S. longline vessels permitted under the Pelagics FMP fishing north of the equator are required to deploy all longline gear such that the “sag” (deepest point) between any two floats is at least 100m (328.1 ft.) below the sea surface and the length of each float line used to suspend the longline beneath a float must be longer than 20m (65.6 ft.), with a minimum of 15 branch lines deployed between any two floats when fishing with monofilament gear or a minimum of 10 branch lines deployed between any two floats when fishing with tarred-rope basket gear.
    - Possession of light sticks, including any type of light emitting device including any flourescent “glow-bead” chemical or electrically powered light type product, is prohibited on board all U.S. longline vessels permitted under the Pelagics FMP during trips north of the equator.
    - Possession or landing of more than 10 swordfish per trip by any U.S. longline vessel permitted under the Pelagics FMP is prohibited.

Additionally, NMFS has decided to issue rules to require that:

- Operators of all U.S. longline vessels permitted under the Pelagics FMP are prohibited from fishing with longline gear during the months of April and May in the area bounded on the south by the equator, on the west by 180 W. longitude, on the east by 145 W. longitude, and on the north by 15 N. latitude.
- The transhipment to vessels registered for use under a western Pacific receiving vessel permit of pelagic fish caught by longline gear within the closed area during April and May is prohibited.
- Operators of all U.S. longline vessels permitted under the Pelagics FMP are required to cease gear retrieval if a sea turtle is discovered hooked or entangled on a longline until the turtle has been removed from the gear or brought onto the vessel’s deck.
- Operators of U.S. longline vessels with a working platform 3 feet or more above the sea surface are required, if practicable, to use a dip net meeting NMFS’ specifications to hoist a sea turtle onto the deck to facilitate the removal of the hook and/or to revive a comatose sea turtle.
- Operators of U.S. longline vessels with a working platform less than 3 feet above the sea surface are required, if practicable, to ease a sea turtle onto the deck by grasping its carapace (shell) or flippers to facilitate the removal of the hook and/or to revive a comatose sea turtle.
- The re-registration of a Hawaii-based longline vessel that has been deregistered from a Hawaii longline limited access permit after March 29, 2001, is allowed only during the month of October.

[25] http://swr.ucsd.edu/piao/eis/rod.htm

- Operators of all U.S. longline vessels permitted under the Pelagics FMP are required to annually attend a protected species workshop, obtain a certificate documenting completion of the workshop, and carry the certificate or a copy on board the vessel.
- Operators of all pelagic fishing vessels fishing with hooks for pelagic management unit species within U.S. EEZ waters of the western Pacific region are required to carry and use line-clippers and wire or bolt cutters capable of cutting through fishing hooks, and must remove all hooks from sea turtles as quickly and carefully as possible or cut the line as close to the hook as possible. In addition, the operators are required to handle all incidentally taken sea turtles brought aboard for dehooking and/or disentanglement in a manner to minimize injury and promote post-hooking survival.