SFP Best Practices Report:

Minimizing and managing the impact of fisheries on marine food webs

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Photograph Credit: Duncan Leadbitter

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Forward

"Look deep into nature, and then you will understand everything better." Albert Einstein

The majority of our planet is covered by the seas and our relationship with the life within them has always been close given our reliance on marine species for food and raw materials. It is ASDA's belief that we have to respect our impacts on the complex inter-relationships that sustain the marine ecosystem. This report signposts the ways forward towards better, more inclusive approaches to fisheries management.

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Executive Summary

Ecosystem-based fishery management (EBFM), also referred to as the ecosystem approach to fisheries (EAF), considers all the living and non-living components of a marine community when managing fisheries. Target species and the ecosystems in which they live are inextricably tied, and fishing affects ecosystems in ways beyond just the removal of the targeted species. These indirect effects, along with other anthropogenic effects like coastal development and pollution, may cumulatively have a greater impact than direct fishing pressure alone for some species. The effect of fishing on the dynamics and health of marine food webs is an important consideration in EBFM.

The effect of fishing on food webs rarely grabs headlines in the media. However, as these impacts are better understood, the issue is expected to be raised more publicly by scientists and activist environmental non-governmental organizations (NGOs). The challenge up to this point has been a lack of data and clear documentation. Negative effects of fishing on food web dynamics may occur over long time frames. These effects are not as apparent as other fishing impacts to the ecosystem, like trawling through a sensitive coral habitat or catching dolphin in a net while targeting tuna. However, acute impacts, such as intense fishing in a confined area in a short time frame, can also cause disruption to marine food webs. Regardless of the type of effect, this paper defines adverse fishing impacts to food webs as those that alter ecosystem resilience and function in a negative way.

Ecosystem-wide food web impacts can begin at any point in the food web. Removal of top predators can destabilize the food web by allowing for the explosion of their prey populations, which can then cascade down through the food web. Removal of prey species at the bottom of the food web can deprive predators of food, having negative ramifications for their populations. But even the removal of competitors from within the middle of the food web can have a ripple effect as their niches are filled by other species. Regardless of which situation may be occurring, scientists recommend understanding the food web from which fish are being removed and setting management measures to maintain ecosystem function and health.

Complex models to simulate ecosystem and food web dynamics are being developed all over the world. While they can be very informative and a useful tool for managers when making decisions, they require significant data inputs. Information on abundance, distribution, and diet is needed across multiple species. Some data and tools are available to understand the impacts and to minimize adverse impacts, but more is needed. Yet, managers can take action to consider fishing impacts on marine food webs with information and tools available today. Simple ecological risk assessment methods for data-deficient fisheries have been developed and are increasingly used to guide EBFM. In addition, precautionary management measures can be put in place to enable some harvest while longer-term data collection and monitoring programs are implemented.

Conventional fisheries management follows a single-species approach with a total allowable catch (TAC) set annually in order to maximize the harvest of the target species without depleting the fish population. Generally, fishing impacts to marine food webs are not clearly factored into conventional harvest scenarios, but this is changing. In this report, Sustainable Fisheries Partnership (SFP) provides the following case studies where fishing effects on the marine food web are or should be considered when managing the fisheries.

- The Antarctic krill fishery is managed with precautionary limits that enable the harvest of krill while preserving its role as a key prey species for many other species in the ecosystem. A model that features krill at the center of a food web is being developed.

- Heavy fishing on cod and other high trophic level species in the northwest Atlantic have led to a drastic restructuring of the entire food web. After such a drastic restructuring of the food web it can be difficult, if not impossible, to restore ecosystems to their original state.

- Models have been constructed that describe pelagic food webs in the Eastern Pacific Ocean. Changes in food web dynamics play an important role in fluctuations of tuna population size, and must be considered as management regulations are created.

- A number of ecological indicators have been identified as key factors in the status of wild Pacific salmon populations. These indicators are gradually being integrated into management in a move towards EBFM.

- Continued harvest of Barents Sea capelin combined with a climate-driven downturn in the population size may have contributed to the collapse of the fishery in the late 1980s. Capelin are the primary food source for cod, a major fishery in the Barents Sea. Fishery managers now have a control rule in place requiring a moratorium on harvest when the population shrinks below a minimum threshold. This control rule ensures that there is enough capelin to produce future generations (allowing the fishery to re-open in a few years) and provide food for Barents Sea juvenile cod.

A number of best management practices are drawn from the literature and case studies. To sustain marine food webs, fisheries management uses (1) depictions of trophic links and biomass flows for food webs, (2) a management framework with environmental targets for food webs and ecological indicators for measuring progress towards those targets, and (3) alignment of harvest scenarios and catch levels to meet those environmental targets.

Seafood buyers can support best practices in fisheries to conserve food webs with the following practical actions:

1. Prioritize source fisheries that have the most urgent need to address fishing impacts on food webs as part of EBFM.

2. Where a significant negative impact of fishing on a food web is suspected and EBFM is not being applied, encourage fishery regulators to consider precautionary management measures.

3. Encourage fishery regulators to identify ecological indicators and set environmental targets where they do not already exist.

SFP is available to assist companies and provide guidance for taking these actions.

Introduction

Ecosystem-based fishery management (EBFM), also referred to as the ecosystem approach to fisheries (EAF), considers all the living and non-living components of a marine community when managing fisheries. Target species and the ecosystems in which they live are inextricably tied, and fishing affects ecosystems in ways beyond just the removal of the targeted species. These indirect effects, along with other anthropogenic effects like coastal development and pollution, may cumulatively have a greater impact than direct fishing pressure alone for some species. The effect of fishing on the dynamics and health of marine food webs is an important consideration in EBFM.

Conventional fisheries management follows a single-species approach with a total allowable catch (TAC) set annually or other controls on fishing, such as the amount of fishing effort in order to maximize the harvest of the target species without depleting the fish population. Generally, fishing impacts to marine food webs are not clearly factored into conventional harvest scenarios, but this is changing. Reports by leading fisheries scientists show that sustained fishing pressure on a few species in an ecological niche is likely to cause evolutionary changes, loss of biodiversity, and reduced ecosystem stability (Garcia et al. 2012; Zhou et al. 2010). The single-species approach is resistant to change because it reflects the operating characteristics of industrial fishing, which of course targets particular species at particular sizes to supply seafood products worldwide. Nevertheless, many fisheries are grappling today with the challenges of adapting management to respond to declining abundance of target species and changes in catch composition over time.

EBFM recognizes there are alternative management scenarios for sustainable fisheries that can slow or prevent disruptive fishing impacts on ecosystems. Unlike conventional management approaches for monitoring fishing impacts on single-species targets, EBFM considers cumulative natural and anthropogenic impacts on different species or sectors to maintain healthy, productive, and resilient ecosystems (McLeod et al. 2005). EBFM improves existing management frameworks by extending the conventional fisheries management paradigm to one that covers all components of the ecosystem instead of just the target species (Garcia et al. 2003).

Framing for EAF was developed at the Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem in 2001, where the key elements of the approach were defined as: (1) goals and constraints that characterize the desired state of fisheries; (2) conservation measures that are precautionary, take account of species interactions, and are adaptive; (3) allocation of rights to provide incentives for conservation; (4) decision making that is participatory and transparent; (5) ecosystem protection for habitat and species of special concern; and (6) management support, including scientific information, enforcement, and performance evaluation (Sinclair and Valdimarsson 2005). Fisheries Ecosystem Plans were proposed as a vehicle for integrating management efforts at multiple levels from the local community to the ecosystem (Sissenwine and Mace 2001).

Observable, widespread declines in the status of species, habitats, and ecosystem function in the marine environment have led to calls for EBFM or EAF as a solution for some of what ails the oceans (Ruckelshaus 2008). In the mid-1990s, the growing number of high-profile failures in single-species fisheries management led to efforts to mandate improvements in governance and a broader, more ecological approach. This requires tools to synthesize and combine data from models, field studies, and single-species stock assessments into a larger framework to understand dynamics at the ecosystem level (Garcia et al. 2003).

The argument that EBFM could maintain ecosystem structure—thus allowing the ecosystem to maintain redundancies and resilience to environmental change—is appealing but not well tested (Ruckelshaus 2008). This is in the sense that few fisheries are managed yet with an ecosystem-based approach and researchers are also grappling with the questions about ecosystem structure, redundancies, and resilience. Despite a long history of intense discussions over implementing EBFM, it is still the case today that the vast majority of fisheries are managed as single-species target fisheries. Pauly et al. (2001) had predicted that adoption would be hampered by the lack of a new, clearly defined approach that is similar to managing fisheries for a maximum sustainable yield of the target species, and because no consensus had been reached around ecosystem "reference points," or targets against which to measure sustainability. Pikitch et al. (2004) stated a need to derive and develop ecosystem-based standards, reference points, and control rules analogous to single-species decision criteria. On the other hand, some fisheries scientists called for significant reforms in fisheries management methods that require the conventional paradigm to change, like shifting from selective fishing (where only specific species and sizes are harvested) to balanced exploitation (where fishing mortality is distributed across the widest possible range of species, stocks, and sizes in an ecosystem) (Garcia et al. 2012; Zhou et al. 2010) or to a benefits-oriented framework where social and economic benefits are maximized instead of harvest (Staples and Funge-Smith 2009).

The World Summit of Sustainable Development in 2003 called for development of EBFM/EAF by 2012, emphasizing: (i) the elimination of destructive fishing practices, (ii) the establishment of marine protected areas (MPAs) and other time/area closures for the protection of nursery grounds, (iii) the adoption of coastal land-use and watershed planning, and (iv) the integration of economic sectors into marine and coastal area management (Garcia and Cochrane 2005).

Though EBFM has not been fully implemented, fisheries management is changing around the world. In the US, optimum yield of fisheries was redefined in 2007 with the reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act to take into account maintenance of marine ecosystems. In 2010, President Obama signed an executive order implementing a new National Ocean Policy for the United States that establishes EBFM as a foundational principle for ocean resource management. In Europe, ecological indicators are starting to be incorporated into fisheries management to help fisheries to meet environmental targets. European fisheries will soon be operating in the context of the European Marine Strategy Framework Directive (European Parliament 2008), which aims to protect marine biodiversity by achieving "Good Environmental Status" for the EU's marine waters by 2020, namely on biodiversity, food webs and seabed habitat, among others. These developments reflect high-level policy advances for broader consideration of negative fishing impacts on food webs.

Fishing impacts to marine food webs are uneven as some species and ecosystems are more sensitive to fishing removals than others. Sometimes fishing a resilient target species has unintentional impacts for other species. Today it is known generally that unbalanced harvests in species, sexes, and sizes can diminish marine life, genetic biodiversity, and ecosystem processes and structure (Garcia et al. 2003. 2012), and conversely that fishing in a balanced manner can maintain both fishing and ecosystem processes and structure.

While fishing impacts on marine food webs are inevitable, data and tools are available to understand the impacts and to minimize adverse impacts. As fisheries management shifts toward an ecosystem-based approach, consideration for maintaining ecosystem resilience and function will increase.

Objectives and approach of this report

This report presents ways that fishing impacts on food webs are and can be addressed in fisheries science and management worldwide. The objectives are to (1) review the state of the science, (2) present case studies of fisheries where managers are or should be considering effects on the food web, and (3) identify practical actions that can be taken by the seafood industry to support best practices in fisheries for conserving food web function and resiliency.

Fishing Impacts on Food Webs

"If we manage a stock in a vacuum and don't take linked biological, physical, and/or chemical components in the system into account, we will have "sub-optimal" management results." (NOAA 2010)

Food webs represent the biological organization of an ecosystem. Intensive fishing pressure can lead to large-scale restructuring of marine communities (Fulton et al. 2005). Fishing may systematically or episodically reduce the presence of particular species in a marine food web and lead to changes in predator-prey relationships. These relationships are dynamic and change with accessibility of the potential prey to the predator and the encounter rates between them. Fishing can affect several factors at once, including the abundance, size composition, and spatial distribution of predators and prey species. An alteration to any of these factors could result in changes to predator-prey relationships, and therefore the availability of the species within food webs and to commercial fisheries.

For almost every marine ecosystem, there is a single keystone species or small group of species that has a disproportionately large effect or role on its environment relative to its abundance (Paine 1995). These species can play a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community. Within a given ecosystem, keystone species can be found at the top of the food web (as an apex predator), toward the bottom (as prey), or somewhere in between.

More than 50 years of fishing pressure on high trophic species has led to observed declines in apex predators like tunas and sharks in the North and Central Pacific Ocean and with corresponding increases in faster-growing prey species in pelagic food webs (Cox et al. 2002; Essington et al. 2002; Polovina et al. 2009). When Kitchell et al. (1999) looked into the large pelagic ecosystem in the North Pacific Ocean to identify keystone species, they found that the most important components of the food web were the higher biomass species that were being exploited (yellowfin and skipjack tuna). Sharks and larger tunas that were being harvested had less effect on ecosystem and food web dynamics (Kitchell et al. 1999). While there is still much debate on the consequences of apex predator removals from fishing (Myers and Worm 2003; Sibert et al. 2006), there is agreement on the importance of managing and rebuilding fish stocks (Worm et al. 2009) and understanding possible effects of fishing pressure on the ecosystem (Howell et al. 2012; Polovina et al. 2009, 2011).

State of the science

Although a global consensus has not been reached around implementation of EBFM, science has provided support for many of the necessary components. Existing scientific studies are available to inform fishery management regimes about trophic declines in marine ecosystems. This has its roots in ecosystem modeling, the scientific examination of ecosystem-scale trends like fishing down food webs and fishing through food webs in the marine environment, and the use of ecological indicators to assess the health of ecosystems.

Significant advances in the scientific work to support consideration of food webs in management occurred in the late 1990s, led by Carl Walters, Villy Christensen, and Daniel Pauly. Walters et al. (1997) developed dynamic models of exploited ecosystems based on the concept that the impacts of fishery removals could be modeled with trophic mass-balance assessments; in other words production of a given species is either harvested by fisheries or consumed by predators, so increasing fishery removals must result in reduction in consumption by predators. Ecopath, Ecosim, and Ecospace software followed as tools for evaluating ecosystem impacts from fishing (Pauly et al. 2000). Ecopath is a tool that creates a model of an ecosystem and describes the flows within the food web. Ecosim takes the results of the Ecopath assessment and makes a dynamic ecosystem model where variables can be changed to explore past and future impacts of fishing and environmental disturbances, as well as to explore optimal fishing policies (Christensen and Walters 2004). Ecosim models can also be replicated over a spatial map grid (Ecospace) to allow exploration of policies such as marine protected areas (Christensen and Walters 2004).

Hollowed et al. (2000) tested four types of multispecies models to determine their ability to evaluate the causes of shifts in marine fish production. They found that compared to single-species models, multispecies models improved estimates of natural mortality and recruitment; resulted in better understanding of spawner-recruit relationships and of variability in growth rates; gave alternative views on biological reference points; and provided a framework for evaluating ecosystem properties. The authors point out that marine populations are regulated by competition for food, predation, and environmental variability, and impacts differ between life stages and geography. In order to truly be successful, multispecies models must be able to accommodate this variability.

In 2005, Myers and Worm looked at large, predatory species sensitive to fishing pressure in the Northwest Atlantic Ocean, like sharks, to more closely observe food web effects from fishing. Their results indicated that management of multispecies fisheries should be tailored to the most sensitive, rather than the more robust, species in order to initiate recovery for severely depleted communities, and that reductions in fishing mortality and bycatch mortality should be accompanied by protection of key areas.

The concept of fishing down the food web became widely known and of concern as a global issue from a 1998 article in *Science* reporting that the mean trophic level of the species groups reported in global fisheries landings had declined from 1950 to 1994 and reflected a gradual transition in landings from long-lived, high trophic level, fish-eating bottom fish to short-lived, low trophic level invertebrates and plankton-eating pelagic fish (Pauly et al. 1998). Fishing down food webs leads at first to increasing catches, then to a transition to stagnating or declining catches (Pauly et al. 1998). Caddy et al. (1998) responded that this hypothesis should be viewed with caution because changes in harvest are not necessarily indicative of changes in the ecosystem (fishing technology and market demands lead to shifts in fishing practices), and not all changes in the ecosystem are the result of fishing pressure (natural environmental fluctuations can change the ecosystem).

In 2006, Essington et al. analyzed trends in fishery landings in 48 large marine ecosystems worldwide and showed that, while fishing down the food web by depleting high trophic level fisheries and replacing them with lower trophic level fisheries does occur, sequential addition of low trophic level fisheries is the more common mechanism underlying declines in mean trophic levels of landings. He called this "fishing through the food web" to clarify that fishing on high trophic level species can continue, even though the mean trophic level of the landings is decreasing. While this may seem more benign than elimination of high trophic level fisheries through overfishing, fishing through the food web may still cause conflicting demands for resources as fisheries targeting species at multiple trophic levels are sure to impact one another and other parts of the ecosystem.

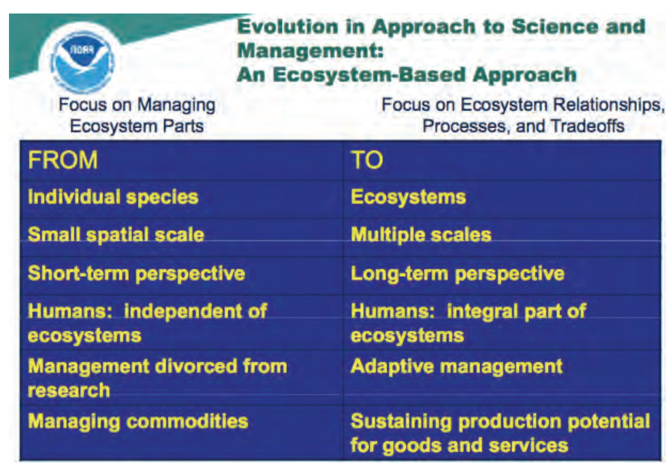
Smith et al. (2011) explored the effects of fishing on low trophic level species (representing 30% of marine capture fisheries) on marine ecosystems, including marine mammals and seabirds, and on other commercially important species in five well-studied ecosystems. They found that fishing these low trophic level species at conventional target levels can have large impacts on other parts of the ecosystem. The impacts are particularly serious when the target species constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web. Their results indicated that halving exploitation rates can result in much lower impacts on marine ecosystems while still yielding 80% of the conventional target.

To factor fishing impacts on food webs into fisheries models requires not only the availability of detailed knowledge of predator-prey dynamics in marine environments but also decisions about ecological indicators that can be used to quantify the impacts of fishing on the ecosystem, as well as environmental targets, or reference points, against which to measure the indicators. Coll et al. (2010) demonstrated how a set of simple ecological indicators could be used to rank and compare exploited ecosystems for the purposes of EBFM. Similarly, Bundy et al. (2010) compared six ecosystem indicators to measure trends over time, but utilized a decision-tree approach to define an initial ecosystem state (impacted or non-impacted) and then classified the ecosystem status as improving, stationary, or deteriorating. Fisheries models are evolving and policy makers in the United States, Europe, and at regional fisheries management organizations are starting to work with ecological indicators and to specify what they need from models to support an ecosystem approach. Theoretical models are available to describe the status of marine ecosystems on the basis of their food web components but are only starting to provide the scientific basis for these indicators and targets (Pikitch et al. 2012; Smith et al. 2011).

Incorporating food web impacts into fisheries management

Conventional fisheries management follows a single-species approach with a total allowable catch (TAC) set annually or with other controls on fishing, such as the amount of fishing effort, in order to maximize the harvest of the target species without depleting the fish population. Generally, fishing impacts to marine food webs are not clearly factored into conventional harvest scenarios, but this is changing. Ideally fisheries managers consider not only the status of the target species population but also the trophic linkages in the fishing environment including the strength of interactions between predators and their prey in response to fishing pressure, as well as other drivers of stability in the fishing ecosystem like the connectivity between biogeochemical and physical processes (Gilman et al. 2012). The information systems needed to do this are emerging, because a shift toward an ecosystem modeling of fisheries is underway in the scientific community, though is not yet fully accepted or integrated in conventional fisheries management. Scientists and managers are gradually incorporating the components that consider food webs into traditional management in a gradual shift to EBFM.

The use of tools that consider information from diverse scientific disciplines is helping to enact a transition from the single-species to ecosystem approach to fisheries (Figure 1).



FROM	TO
Individual species	Ecosystems
Small spatial scale	Multiple scales
Short-term perspective	Long-term perspective
Humans: independent of ecosystems	Humans: integral part of ecosystems
Management divorced from research	Adaptive management
Managing commodities	Sustaining production potential for goods and services

Figure 1. Transition from the single-species to ecosystem approach to fisheries

Source: NOAA (2010) NEFSC EBFM brochure

Modeling has predicted that employing conventional fishing reference points for a maximum sustained yield for low trophic species will cause large impacts on other parts of the ecosystem, especially where these species represent much of the biomass in the ecosystem or are highly connected in the food web (Smith et al. 2011; Walters et al. 2005). By contrast, in Australia's Northern Prawn Fishery, several low trophic species are managed together (rather than singly) with mortality rates driven by bio-economic objectives and this has proved an effective strategy for keeping the target fishing resource at high levels. The fishery's impacts on the ecosystem are monitored on a regular basis with ecological risk assessment, and this practice is credited with keeping fishing costs down and achieving strong conservation outcomes (Cathy Dichmont, CSIRO, personal communication, 2012).

The concept of balanced harvest is showing signs of reaching a global consensus for ecosystem-based fisheries management. It broadens the conventional perspective of selectivity beyond fishing operations and single-species target fish stocks to the integrated scale of ecosystem productivity and impacts. In a balanced harvest scenario, fisheries would capture species, sexes, and sizes in proportions that roughly match their occurrence in the ecosystem. With fishing spread over more groups and sizes, overall yields are higher and impacts of fishing—such as population extirpations (local extinctions) and biomass depletion—are lower across a broad range of fishing mortalities (Garcia et al. 2012).

Several regions of the world with more advanced fisheries management systems are working toward integrating marine food web function into the decision-making process. The new Marine Strategy Framework Directive of the European Union's Integrated Maritime Policy (ICES 2013) calls for European fisheries to achieve Good Environmental Status for biodiversity, food webs, and seabed habitat (Defra 2012). The European Commission has developed criteria for marine strategies that include a comprehensive set of environmental targets.

To support the implementation of the Common Fisheries Policy, European fisheries still need models that incorporate the important interactions at specific stages and scales in order to supplement the information provided by single-species models and to understand tradeoffs between fishery yields, biodiversity, food webs, and the state of seabed habitat. Multispecies models are needed to generate improved estimates of natural mortality and recruitment, to better understand spawner-recruit relationships and variability in growth rates, to incorporate alternative views on biological reference points, and to develop a framework for evaluating ecosystem properties (Defra 2012).

Although specifics are still weak, the elements of a general framework for managing European fisheries have been written. A large-scale evaluation by the European Commission identified the state of seabed habitats, biodiversity, and fish communities (food webs) as the components of marine ecosystems most likely to be impacted unsustainably by fishing (Defra 2012). Results of the evaluation led to the conceptualization of new models and modification of existing models to predict (1) how the intensity and distribution of fishing activity affected biomass and production of seabed habitats, (2) how the structure of fish communities and food webs changed with fishing mortality, and (3) how the biomass and reproductive potential of sensitive fish species changed with fishing mortality (Defra 2012). These indicators will lead to new monitoring protocols for fisheries to ascertain fishing impacts on food webs.

The US North Pacific Fisheries Management Council uses a voluntary Fishery Ecosystem Plan (FEP) with predator-prey objectives to help manage fisheries around the Aleutian Islands. These important steps towards integrating secondary impacts of fishing in management reflect a growing awareness of the need to consider fishing impacts on ecosystem components like food webs. In some cases, regulatory changes towards integrating marine food webs in fisheries management have been more reactive than proactive. Preceding adoption of the FEP, US environmental groups successfully sued the government because it did not sufficiently consider the effects of fishing on the prey availability for Steller sea lions. Eventually, this led to cod, mackerel, and pollock catch limits to ensure sufficient food for Steller sea lions around the Aleutian Islands, among other measures.

Outstanding issues in accounting for food web dynamics

- Theoretical models are available to describe the status of marine ecosystems on the basis of their food web components; however, it is still uncommon for fisheries to define ecosystem-based environmental targets and ecological indicators for those targets.

- Fisheries managers need accepted models that incorporate the important interactions at specific stages and scales in order to supplement the information provided by single-species models and to understand tradeoffs between fishery yields, biodiversity, food webs, and the state of seabed habitat. Models have been available for years but have not been accepted widely for management use, often because the level of proof needed to justify taking a management action is very high. Often clearer political, social, and economic reasons are cited as reasons for taking action.

- Multispecies models are needed to generate better estimates of natural mortality and recruitment in order to better understand spawner-recruit relationships and variability in growth rates, to incorporate alternative views on biological reference points, and to develop a framework for evaluating ecosystem properties.

- Assessment of fishing mortality for rare and sensitive species remains a significant challenge requiring detailed knowledge of food web dynamics. This would require a high level of science input.

- Despite reliance on complex models and the perceived need for better modeling and more data, managers can take action to consider fishing impacts on marine food webs with information and tools available today. Simple ecological risk assessment methods for data-deficient fisheries have been developed and are increasingly used to guide EBFM. This applies to fisheries in developed and developing countries. What is missing is a better understanding of precaution in fisheries management with respect to sustaining food webs. For an example of how precautionary action is taken despite lack of data, see the Southern Ocean krill fishery case study of this report.

Options for incorporating food web concerns into fishery management

- ***Create Ecosystem Models***
  Use tools such as Ecopath, Ecosim, and Ecospace to create models that describe the ecosystem and allow scientists and managers to modify components of the ecosystem to explore past and future impacts of fishing and environmental disturbances as well as to explore optimal fishing policies.

- ***Apply Multispecies Management***
  Understanding and making trade-offs between the overall ecosystem yield and the status of individual species in the ecosystem is an approach seen in multispecies fisheries management, where the relationship between the yield and the relative depletion of species in an ecosystem is considered (Myers and Worm 2009). There is a need to make explicit and well-informed decisions on the balance, and not to deplete any species to the point where irreversible or slowly reversible change happens. Multispecies management often must be tailored to the most sensitive rather than the more robust species in order to initiate recovery for severely depleted communities.

- ***Avoid Fishing Down or Through the Food Web***
  Mean trophic level of landings is often looked to as an indicator that signifies changes in fishery impacts on ecosystems. The mean trophic level of the species groups reported in global fisheries statistics declined 1950–1994, reflecting a gradual depletion in long-lived, high trophic level fish and transition to fisheries on short-lived and low trophic level invertebrates and planktivorous pelagic fish (Pauly et al. 1998). This concept, known as fishing down the food web, may not be as common as once thought (Essington et al. 2011; Branch et al. 2010), but is still a viable concern that should be investigated. Another common mechanism underlying declines in mean trophic levels in marine ecosystems is the serial addition of low trophic level fisheries (Essington et al. 2006). The cumulative fishing impacts cause mean trophic levels of landings to decline, and can be an indicator for conflicting demands for resources. Changes in mean trophic level of landings should trigger investigation of the

cause of the decline to ensure that neither overfishing of high trophic level species nor conflicts between fisheries operating at different trophic levels is occurring.

- ***Increase Biomass Targets for Low Trophic Level Species***
  Fishing low trophic level species at conventional target levels can have large impacts on other parts of the ecosystem. The impacts are particularly serious when the target species constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web. Halving exploitation rates in low trophic fisheries can result in much lower impacts on marine ecosystems while still yielding 80% of the conventional target (Smith et al. 2011). That reduction in effort may only be necessary temporarily to increase biomass to an increased target.

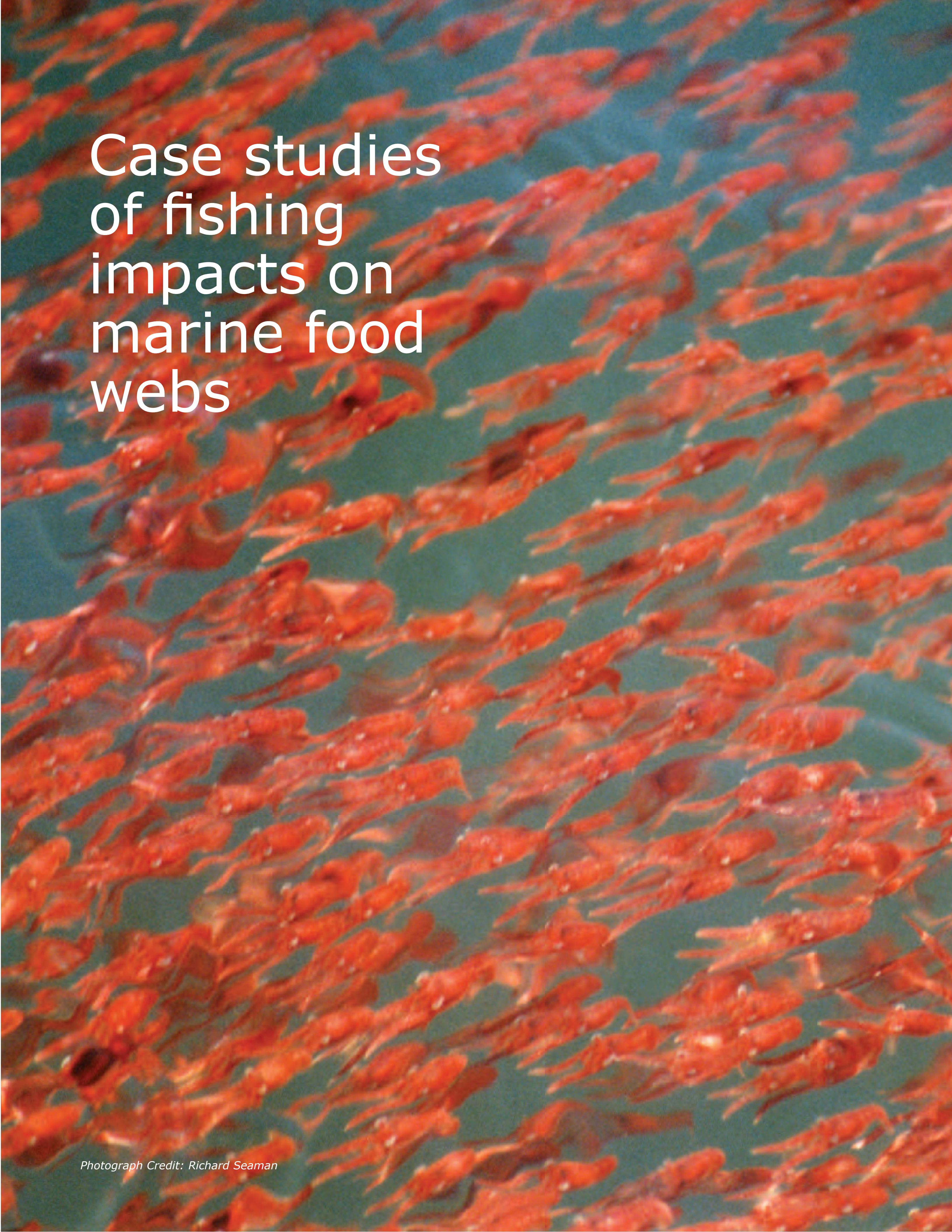
- ***Consider temporal and spatial fishing closures***
  Closures can be used to prevent the depletion of prey in areas or times of particular importance to foraging species. For example, fishing grounds could be closed near seabird and marine mammal foraging areas during breeding seasons or other times when those predators are highly reliant upon that prey.

- ***Develop Ecological Indicators to Monitoring Fishing Impacts***
  To factor fishing impacts on food webs into fisheries models requires not only the availability of detailed knowledge of predator-prey dynamics in marine environments but also decisions about ecological indicators that can be used to quantify the impacts of fishing on the ecosystem. Knowledge of a fishery's context (ecological, environmental, historical) is crucial to interpreting indicators correctly, while disentangling the effects of fishing and of the environment.

- ***Set Environmental Targets***
  Once ecological indicators are determined, targets must be established against which to measure the indicators to determine the state of the ecosystem, impacts of fishing, and progress of management measures.

The case studies in the following section give further examples of how consideration of food web dynamics has been or could be incorporated into fisheries management.

Case studies of fishing impacts on marine food webs



Photograph Credit: Richard Seaman

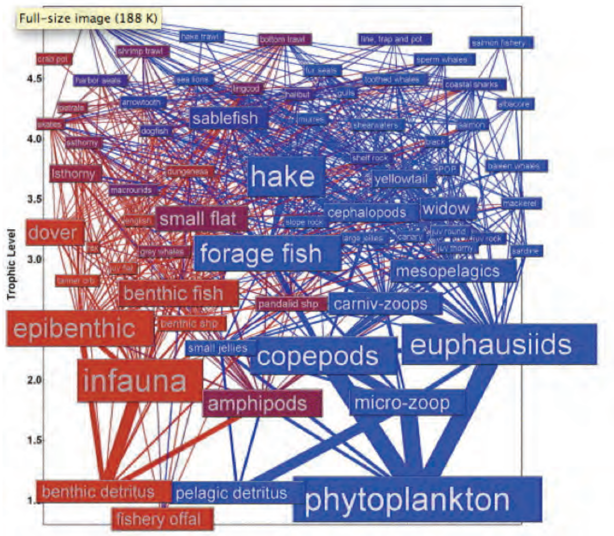


Figure 2. A graphical depiction of a food web in the Northern California Current

Source: Field, JC, RC Francis, and K Aydin. 2006. Top-down modeling and bottom-up dynamics: Linking a fisheries-based ecosystem model with climate hypotheses in the Northern California. Current Progress in Oceanography 68(24):238-70. http://www.sciencedirect.com/science/article/pii/S0079661106000085

"Models are guidelines in lieu of nice controlled experiments. The best examples of managing fisheries for food web impacts are the simple ones where fisheries respond to bottom-up drivers of environmental change in order to keep the target stock thriving."
(Tim Essington, personal communication, 2012)

Ecosystem approaches for conserving food webs vary widely in fisheries management. Some respond to the need to recover a collapsed stock and others are designed simply to better understand the ecosystem consequences that result from the rapid removal of a trophic layer by fishing. These case studies describe different ways that fishing impacts on food webs are identified in research and used to inform fisheries management: krill in the Southern Ocean, cod in the northwest Atlantic, large pelagic fish in the Eastern Pacific Ocean, wild Pacific salmon in the Bering Sea, and forage fish generally (herring, sardines, anchovy, menhaden).

The krill fishery of the Southern Ocean

The krill fishery in the Southern Ocean is a well-known example of a low trophic level fishery that is managed with consideration of fishing impacts to food webs. Krill are zooplanktons that move in dense shoals that can stretch for kilometers. They are found in Antarctic waters between the continent and the polar ice front generally within depths of 100m or less. Krill are filter feeders and consume phytoplankton (generally single-celled, plant-based organisms) and other zooplankton (small shrimps and larvae). They also graze on algae under the ice. Krill are a food source for a variety of organisms in the ecosystem such as whales, seals, fish, and birds. The Antarctic marine food web is depicted in Figure 3.

Spatial management and high biomass reference points, meaning the biomass targets for krill are much higher than they would be if krill production was the sole focus, are used in the krill fishery of the Southern Ocean to manage the availability of krill for all predators (Peatman et al. 2011). The fishery is not yet managed with a supporting model that features krill at the center of a food web, but such a model is in the early stages of development by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Atkinson et al. 2012). For practical purposes, catch levels in the krill fishery have become more precautionary over time, and the management process has become illustrative for all fisheries.

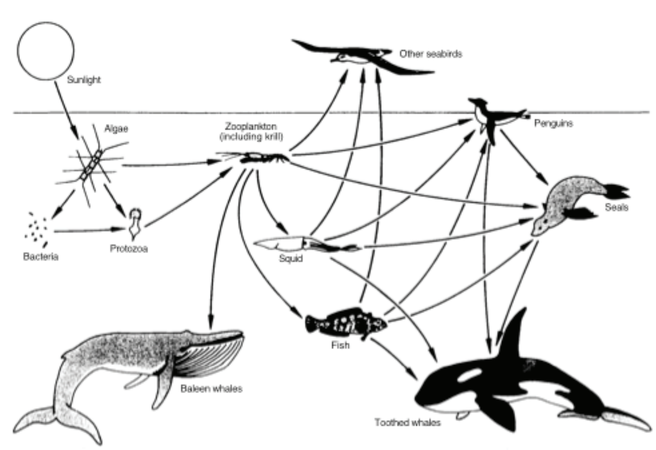


Figure 3. The Antarctic marine food web with krill at the center.

Source: Kock, K-H. 2000. Understanding CCAMLR's Approach to Management. CCAMLR. Available at http://archive.ccamlr.org/pu/E/e_pubs/am/toc.htm.

Management started with multiple attempts to clarify the biomass estimate and potential catch for krill, in a long chain of events (Miller et al. 2004). CCAMLR Conservation Measure 32/X set a 1.5 million metric ton precautionary catch limit on krill (*Euphausia superba*) in Statistical Area 48 with a measure that facilitated the future application of precautionary limits to subareas or local areas (Hewitt and Watters 2001). At that time, krill catch limits were based on trade-offs between adverse impacts to dependent species, like penguins and seals, and the potential for implementation to be delayed by disagreement among member countries. Catch limits based on protective zones, critical periods, predator censuses, and predator-prey models were not considered practical at that time. Changing fishing patterns with protective zones and critical periods would require agreement from member countries (Hewitt and Watters 2001).

By 2008, CCAMLR had published a method for determining spatially structured catch limits to manage the risks of adverse impacts from fishing krill on its predators (Constable 2008). The method provides a common procedure for inserting data, assessment methods, and candidate modeling approaches for assessing yield. Constable proposed the method to CCAMLR as a framework for formalizing the decisions that need to be made in dealing with an ensemble of food web models for providing suitably precautionary advice on how to spatially structure krill fisheries to account for the needs of predators (Constable 2008).

Through CCAMLR, the krill fishery is managed by member states with gear regulations on mesh size and conservation measures that include a vessel monitoring system; a catch documentation for toothfish (*Dissostichus spp.*); and protection of registered vulnerable marine ecosystems in subareas, divisions, small-scale research units, or management areas open to bottom fishing (conservation measure 22-09, from 2012). In 2009, CCAMLR adopted Resolution 31 as an explicit commitment by members to accept conservation measures based on best available science and support the work and results of the scientific committee. This resolution demonstrates that CCAMLR puts science at the forefront of fisheries management, which is unique among regional fishery management boards, even if not yet fully centered on a food web model. The Marine Stewardship Council certified the pelagic trawl fishery for krill in CCAMLR statistical area 48 as sustainable in 2011.

The Marine Stewardship Council certification was controversial precisely due to the central role of krill in the polar food web, where light availability is severely limited for half of the year, reducing the availability of algae to krill. The Antarctic and Southern Ocean Coalition objected to the certification because of uncertainties about potential negative ecosystem effects. In the United States, the North Pacific Fishery Management Council does not permit a polar krill fishery, because krill is a main food source for whiting, an important commercial fishery (Tim Essington, personal communication, 2012). This is a good illustration of the priority that is assigned to target species in fisheries management, and in fisheries science as well. In both the Antarctic and North Pacific, fishing impacts on food webs are the deciding factor in the harvest strategies for these fisheries. One strategy is to incorporate low trophic level fisheries into the ecosystem harvest strategy, while the other is to prevent fishing on low trophic level species to maximize the production and harvest of higher trophic level fisheries.

Having the CCAMLR krill fishery certified by the Marine Stewardship Council has drawn more attention to the fishery's remaining deficiencies, which were addressed in the process of corrective actions. For example, the fishery commissioned a comprehensive analysis of larval fish bycatch and an assessment of the risk posed on populations in each fishing area. The results of this study indicated that the level of larval fish bycatch in the krill fishery was highly unlikely to pose a risk to the populations of fish most frequently caught (Hough and Medley 2012). The combination of CCAMLR's science-based management and Marine Stewardship Council certification have created a dynamic for fisheries improvement that is raising the bar for fisheries management worldwide.

Food web changes coincident with the collapse of northwest Atlantic cod

The lack of recovery of several collapsed cod stocks in different geographic areas of the northwest Atlantic Ocean has been attributed, in part, to trophic cascades (Frank et al. 2005). In other words, removal of top predators from ecosystems can result in cascading effects through the trophic levels below, completely restructuring the food web and hindering rebuilding of depleted fish stocks. While cascades have been observed in small-scale or simple food webs, Frank et al. (2005) were the first to observe large-scale system changes. They concluded that the collapse of the benthic fish community in the Scotian Shelf ecosystem off Nova Scotia drove changes in food webs affecting the entire community. In addition to cod, other commercially-fished whitefish species, including haddock, hake, pollock, flounder, plaice, skate, and flatfish, also declined during the mid-1980s to early 1990s. This resulted in the virtual elimination of the ecosystem-structuring role of large bodied predators that had dominated for centuries (Jackson et al. 2001). Following the collapse of whitefish and flatfish, a marked increase occurred in populations of small pelagic fishes and invertebrates like snow crab and northern shrimp that formerly were the primary prey of these whitefish and flatfish. Other effects, like alterations in abundance of herbivorous zooplankton, were seen that match expectations of the removal of the top predator from the ecosystem. For example, size-selective predation on zooplankton by small pelagic fishes and early life stage crab and shrimp was observed (Frank et al. 2005). In addition, seals appear to have benefited from the cod collapse, as they prey on the same small fish and invertebrates as do cod. The depletion of cod reduced predation on those species, making them more available for seals, which have increased exponentially (Bowens et al. 2003). This increased competition for food could have implications for the recovery of cod.

Recovery of northwest Atlantic cod is the responsibility of fisheries managers in Canada and the United States, and a universal approach remains elusive. Management bodies in the northwest Atlantic are facing the challenge of adapting to ecosystem-level transformation. Howell et al. (2011) have said a combination of traditional management methods and ecosystem modeling is needed, along with efficient and regular ecosystem monitoring that will provide effective near- and long-term understanding and forecasts of ecosystem changes.

Clearly, reducing fishing mortality is key to recovery of any overfished stock. Despite closures of many of the main commercial offshore cod fisheries, smaller inshore fisheries have continued on and off throughout the "closures," and some fisheries were temporarily reopened. The biomass of cod had been depleted to such low levels in many of these fisheries, that even these low levels of fishing translate into levels of fishing mortality that continued to hinder recovery of the stocks. Yet, even if fishing mortality were eliminated completely, it remains to be seen whether all northwest Atlantic cod stocks can recover due to shifts in the food web. In addition, preliminary research suggests that because the Gulf of Maine is at the end of the southern range for species such as cod and shrimp, the recent record-breaking ocean temperatures are creating a northern shift in distribution of these species and affecting reproduction (Fogarty et al. 2008; Richards et al. 2012). Some southern species may become more abundant in the region (Jacobsen et al. 2009), introducing new competitors for prey and habitat. Both the US New England and Mid-Atlantic Fishery Management Councils have, since 2011, prepared guidance documents to help adjust Fishery Management Plans into Fishery Ecosystem Plans, which will consider the multitude of forces acting in the system. Implementation of the planning and reform process is an imperative, and should be a priority.

It may not be possible to rebuild all northwest Atlantic cod stocks to what they once were, especially considering the potential impacts of climate change. The collapse and continued low levels of many northwest Atlantic cod stocks, despite reductions or even moratoria in harvest, points to the need to reform fisheries management to maintain ecosystem resilience and function as a main objective, because once lost it may not be possible to recover. If and when northwest Atlantic cod stocks rebuild above biomass limits, careful consideration should be made for balanced harvest across commercially fished species in the food web.

Pelagic food webs in the Eastern Pacific Ocean

"With large pelagics we are trying to understand what the food web is and how it changes over time. We have a model with still a lot of uncertainty but our results help us to learn how to manage with uncertainty. A protocol isn't taking shape yet but we are looking at our data to see if a hypothesis emerges. Diets are changing."
(Robert Olson, IATTC, personal communication, 2012)

More than 50 years of fishing pressure have led to observed decreases in apex predators and corresponding increases in faster-growing prey species (Cox et al. 2002; Essington et al. 2002; Polovina et al. 2009). Robert Olson and colleagues at the Inter-American Tropical Tuna Commission (IATTC) are examining large-scale changes in the pelagic ecosystem in the Eastern Pacific Ocean by investigating predation by and on the yellowfin tuna population. Their work illustrates how managers could consider ecosystem processes and food web dynamics.

The proportion of skipjack and yellowfin tunas in the diets of apex predators such as sharks and billfishes in the Eastern Pacific Ocean is high (Hunsicker et al. 2012). Sharks and billfishes consume a wide size range of tunas, including subadults (young but capable of breeding) that are important for the populations because of their notable contribution to reproductive output. This suggests their diet plays an important role in regulating tuna populations. If sharks are being reduced at a population level over time by fishing, then that should reflect in increased yellowfin and skipjack populations, which should have less predation.

Changes in the prey of yellowfin tuna are also helping tuna scientists to examine coinciding changes in the yellowfin populations in the Pacific Ocean. Formerly, the auxis frigate mackerels (small scombrids/bullet tuna) were the primary prey item for tunas when food web monitoring began in the early 1990s. In the early 2000s, the amount of auxis had greatly reduced in the diet of yellowfin tuna. If these species are being consumed in proportion to what is there, as many argue, then these auxis are fewer than in the past. This seems less likely to be a fishing impact and more likely to be linked to climate change (Robert Olson, personal communication, 2012), which will exert a bottom-up effect on tuna populations.

Olson and colleagues have developed an ecosystem model for the pelagic Eastern Pacific Ocean to address the relative top-down effects of fishing (pressure exerted by predators) and bottom-up effects of environmental forcing (changes in prey availability and type) on the ecosystem. Models of trophic links and biomass flows for food web models are effective tools to evaluate climate and fishing effects on exploited ecosystems (Olson et al. 2010).

Modeled tuna species groups reacted trophically to changes in fishing pressure across scenarios examined by Hunsicker et al. (2012), suggesting that tuna are affected by top-down predation as well as increased prey availability from mid- and lower trophic levels (bottom-up effects). They identified potentially important predators of tunas by the frequency, quantity, size, and age of tunas in their diets and considered the degree that predated tunas could have potentially contributed to the reproductive output of the population. In the model, fishing pressure strongly affected the shark and mid-trophic fish groups, though an increasing trend in shark biomass was predicted. This may reflect the shark finning prohibition in the US, possible recovery of species from previously high mortality (Sibert et al. 2006) or be linked to the proportion of mid-trophic level fish in the diet of the shark groups. Tuna, not sharks, had the greatest impact on mid-trophic level fish through competition and predation (Hunsicker et al. 2012).

These results are important to the collective management of tuna and tuna-like species in the Pacific and Indian Oceans and globally. Although the science and modeling have not yet led to specific management actions or plan changes, they provide insight into the food webs of the pelagic ecosystem and how fishing impacts at one trophic level can affect the availability of species at another trophic level. Even where the scientific advice is clear that catches need to be reduced because a stock was in decline, it has proved difficult to reduce fishing effort. This must change if we are also to account for food web dynamics in fisheries management. Better agreement is needed on precautionary management and desired outcomes at the ecosystem level.

Conserving wild Pacific salmon food webs in the Bering Sea

"The US North Pacific Council's work in the Bering Sea employs not only individual-based species rates but total biomass removal rates to allow forage for sensitive species like Steller sea lions."
(Jeff Polovina, personal communication, 2012)

"For salmon you really need to take an ecosystem approach."
(Daniel Schindler, personal communication, 2012)

The Bering Sea is a high-latitude, semi-enclosed sea that supports extensive fish, seabird, marine mammal, and invertebrate populations and some of the world's most productive fisheries, including nearly half of US catches (North Pacific Research Board 2012). Both climate variability and fisheries have substantially altered the Bering Sea ecosystem in the past (Aydin and Mueter 2007).

Although there is not an open-ocean commercial fishery for salmon in the Bering Sea, many coastal salmon fisheries depend on fish that inhabit the Bering Sea during important parts of their life cycle. Today, wild salmon fisheries in Alaska remain very important to the United States and impacts by fishing on wild salmon food webs are being researched to help explain fluctuations in populations. The following is a summary of some of some of the current projects producing important information that could be used to set ecological indicators to help monitor changes in marine food webs.

Predator-prey dynamics and trophic interactions around Bering Sea fisheries are being researched currently through the Bering Sea Project, a joint project of the North Pacific Research Board and the National Science Foundation in the United States (NPRB 2012; see Figure 4). The project includes a novel approach for predicting the juvenile migration of Bering Sea wild salmon populations based on food web and climatic indicators, shown in Figure 5.

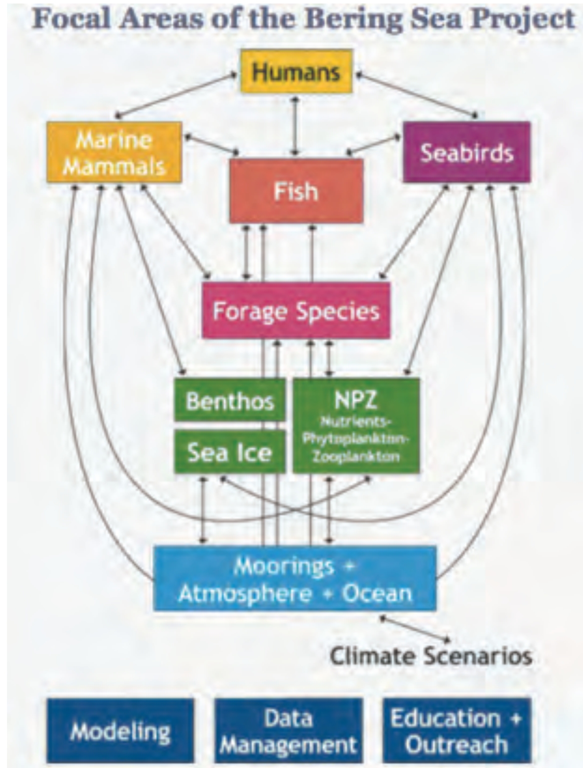


Figure 4: Research focus for the Bering Sea Project

Source: NPRB 2012 http://bsierp.nprb.org/focal/index.html

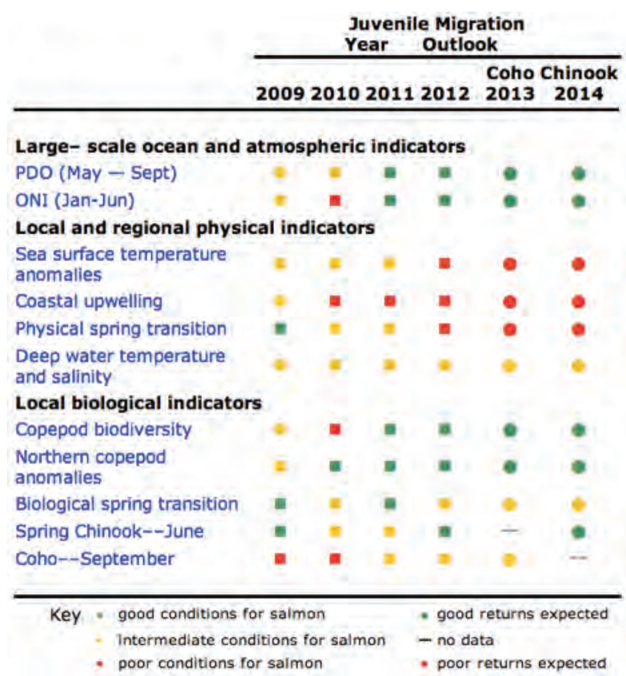


Figure 5. Predicting wild salmon juvenile migration with food web indicators

A closely related research program, the Bering Sea Integrated Ecosystem Research Program (BSIERP) focuses on understanding trophic interactions among colony-based foragers, hot spot foragers, pelagic forage species, pelagic predators, and benthic predators. Research results from the BSIERP are linking climate with physical oceanography, lower and upper trophic levels, and economic outcomes to inform ecosystem modeling (NPRB 2012).

The Bering-Aleutian Salmon International Survey (BASIS) is the North Pacific Anadromous Fish Commission's cooperative research program designed to clarify the biological response of Bering Sea Pacific salmon to climate changes. This research should help clarify how the dramatic fluctuations in growth and survival of salmon populations may be related to overall changes in the Bering Sea and other marine ecosystems.

The US National Oceanic and Atmospheric Administration (NOAA) has objectives to incorporate stock- and age-structure information into a juvenile abundance index for Yukon River Chinook salmon; to assess the energetic status of juvenile Yukon River Chinook salmon; to describe key forage fish species utilized by Chinook salmon; and to identify ecosystem indicators related to juvenile survival and fitness. Results have been integrated for a better understanding of salmon diet, critical nutritional requirements, juvenile distribution, stock structure and changes in juvenile Chinook distribution, condition, survival, and abundance. The findings show significant variation in abundance, survival, and condition, and that migration has changed significantly since 2002.

The above-mentioned research projects are significant for salmon because features of the food web, habitat and oceanographic conditions are known to be key factors in the status of wild Pacific salmon populations, but these factors had not previously been codified as environmental targets and ecological indicators. Robust data sets like these are needed before EBFM can be implemented. Monitoring ecological indicators for Bering Sea wild salmon fisheries through the BASIS program is supporting the development of an ecosystem approach to salmon fisheries management. The information is not yet codified in North Pacific salmon fisheries management; however, it is factored into studies on stock status that inform the process for setting escapement goals. Ecological indicators for salmon are also used in environmental impact statements, for example for protected Steller sea lions.

Fishing impacts on forage fish food webs

Forage fish are small to medium-sized species that include anchovies, herring, capelin, menhaden, and sardines and together make up more than one-third of the world's marine fish catch. Forage fish occupy a central place in marine food webs as the main path for energy to flow from the bottom level of the food web to the higher trophic levels. They feed mainly on plankton and serve as prey to other ocean life, usually forming dense schools, making them easy to catch (Pikitch et al. 2012). Forage fish are used for animal and fish feeds and many other uses in addition to playing a direct role as human food, with the result that fishing on forage fish has expanded tremendously in recent years.

Recently, advice was published on the sustainable management of forage fish fisheries by the Lenfest Task Force on Forage Fish (Pikitch et al. 2012). The Task Force quantified the value of forage fish, both as a human-food commodity and as prey for other commercially-fished species. It also modeled the effects of various fishing strategies on forage fish and their predators. The summary findings emphasized overall that many species in marine ecosystems depend on forage fish as valuable prey and their populations decline when forage fish decline (Pikitch et al. 2012). Other research has suggested that when predator species shift away from a forage fish-based diet to other species, such a shrimp, the growth, condition, and reproductive success of the predator population can be inhibited (Sherwood et al. 2007).

Conventional fisheries management targets and strategies may not be appropriate for forage fish stocks because they have natural, large swings in population size (due to environmental variation) and play a key role in sustaining food webs that should be accounted for.

One example of forage fish management that does account for food web impacts is in the Barents Sea capelin fishery. The fish community in the Barents Sea is relatively simple, consisting of only about 200 species (Pikitch et al. 2012). Capelin is the most abundant forage fish species in the ecosystem, and many other species (cod, herring, seals, sea birds, and marine mammals) depend upon it as a major prey item (ICES 2012). As with many forage fish, capelin has large natural variations in population size, often dependent upon climatic variation, but contrary to other species, it dies after spawning. Barents Sea capelin has supported a large fishery, which targets pre-spawning capelin, for fishmeal and oil since the 1970s, though it has shown cyclical variation in landings. The Barents Sea is also home to one of the largest cod fisheries in the world, as well as a historical herring fishery. Capelin is prey to both cod and herring, thus the three species' abundance and fisheries targeting them are interconnected and affect one another. Recognizing the need to incorporate food web concerns into management, the Joint Norwegian-Russian Fisheries Commission has agreed on a target escapement harvest strategy (a strategy to ensure that a certain amount of fish "escape" the fishery and are able to spawn) where a minimum population size for capelin was established and where there can be no harvest when the population falls below that threshold. This minimum population size is calculated taking into account juvenile cod predation on capelin, thus incorporates some aspect of food web dynamics. On the other hand, the minimum population size does not account for herring or adult cod predation and management regulations do not include a target management reference point as a goal for the harvest strategy (ICES 2012). Nevertheless, this is one of the very few examples of a fishery management system that explicitly accounts for food web impacts.

Key findings from case studies

- Many food web models are available for fisheries management, but to employ them managers require a high level of proof of fishing impacts on other species at the population level. Before that proof is available, research can be done and precautionary measures can be implemented. As illustrated by the Antarctic krill case study, it is possible to harvest lower trophic level species with precautionary harvest limits as a model that features krill at the center of a food web is being developed.

- Fishing impacts may serve as a 'keystone predator' by causing cascading effects through trophic levels that restructure marine food webs. Overfishing on northwest Atlantic cod and other commercially important benthic species resulted in the virtual elimination of large-bodied predators that had dominated the ecosystem for centuries. The food web changed rapidly and dramatically. Today, populations are increasing for small pelagic fishes and benthic macro-invertebrates like snow crab and northern shrimp that formerly were the primary prey of benthic species. After such a drastic restructuring of the food web it can be difficult, if not impossible, to restore ecosystems to their original state.

- Populations can be influenced by predation (top-down effects), prey availability (bottom-up effects), and fishing pressure. Dietary changes can illustrate these impacts, as has been seen in pelagic food webs in the Eastern Pacific Ocean. Changes in food web dynamics play an important role in fluctuations of tuna population size. Prey species are decreasing, potentially due to climatic changes, while apex predators also appear to be at low levels. Mathematical food web models including depictions of trophic links and biomass flows for food webs are useful data to evaluate fishing effects on ecosystem dynamics and are a good step towards EBFM.

- In general fisheries management has yet to establish clear goals for fishing interactions with other species and for sustaining marine food webs. Goal setting is needed to implement EBFM and enable measurement and evaluation of management efforts. The best available science suggests that defining environmental targets and ecological indicators is a sound approach. Features of the food web, habitat, and oceanographic conditions are known to be key factors in the status of wild Pacific salmon populations but these factors had not previously been codified as environmental targets and ecological indicators. Now, these factors have been defined as ecological indicators for these populations and are gradually being integrated into management in a move towards EBFM.

- Reducing harvest on low trophic level species can be a precautionary target for fisheries management, especially when these low trophic level species are keystone species. In the case of the Barents Sea capelin fishery, the target species is a valuable component of the ecosystem as prey for higher trophic levels. Fishery managers have therefore agreed on a minimum population size that ensures there is enough capelin to produce future generations and provide prey for the Barents Sea juvenile cod population.

Best practices in fisheries for sustaining food webs

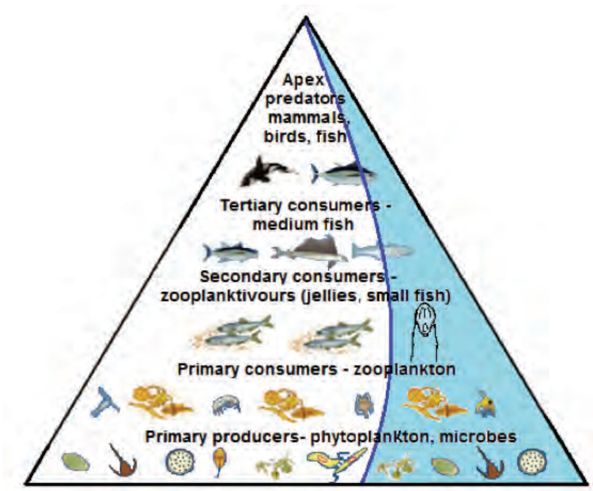


Figure 6. Balancing fisheries exploitation by harvesting at multiple trophic levels

The shaded area indicates fishery removals at sustainable rates according to the ecosystem's natural capacity, which could require developing markets for currently unutilized and underutilized species. This approach also requires accounting for all sources of human-induced mortality (e.g., pollution, habitat destruction etc.), not just those from fishing). Source: Gilman et al. 2013

This report described ways that fishing impacts on food webs are being addressed in fisheries science and management worldwide. The major conclusion of the review is that fishing impacts on marine food webs are only starting to become a factor considered in fisheries management globally. It is not yet the case that predator-prey relationships are commonly factored into harvest scenarios, even though natural mortality rates are predator-, prey- and fishery-dependent (Overholtz and Link 2007), and this has contributed to sub-optimal management planning and trophic declines in ecosystems.

Disruption to marine food webs occurs when the trophic structure of the fishing environment is altered beyond the capacity of the food web to compensate and maintain its necessary structure and function. To sustain marine food webs, fisheries management uses (1) ecosystem-specific depictions of trophic links and biomass flows for food webs, (2) a management framework with environmental targets and ecological indicators for meeting those targets, and (3) alignment of harvest scenarios and catch levels with environmental targets. Incorporating these data and tools into fisheries management will help conserve sensitive species over time and contribute to conservation of food web function needed to sustain commercial target stocks. Working within the current state of the science, it is possible to update conventional fisheries management with new and modified fisheries management plans that can minimize the negative impacts of fishing activities on the trophic structure of marine ecosystems, even when not yet fully implementing EBFM.

Food web impacts should be factored into harvest planning. Environmental targets should be set and ecological indicators will be needed to track progress toward achieving those targets. Fisheries in sensitive environments, for example krill fisheries in polar environments, need biomass targets that are sufficient to meet food web nutritional and energetic needs throughout the year, including the dark 6 months when the availability of algae diet of krill is very low. Fisheries targeting forage fish need catch limits that protect the fish populations that prey upon those small pelagics to ensure that biomass targets are met to sustain the food web. In marine ecosystems with many overlapping fisheries, for example for tunas or salmon, there is a need for broad agreement on sustaining food webs with precautionary management and catch limits that account for fisheries interactions.

With adequate precaution for sustaining marine food webs, safe harvesting rates can be implemented, even where data are limited. Models available today can help managers to optimize fishing yield with a more accurate understanding of species characteristics: diet, condition, survival, distribution, abundance, and variation in each over time. But more and closer monitoring is not the only approach to sustaining food webs. As shown in the CCAMLR case and in fisheries with low information tiers, a precautionary harvest rate can be set to have a very high probability of being safe for the stock and the food web. These management measures can be maintained without additional data and monitoring, but allow for the collection of that additional data and monitoring to facilitate future movement towards comprehensive EBFM. Where there is a desire to fish more aggressively, extra information is needed to reduce uncertainty in knowing the extra fishing effort will not negatively affect food web function and resiliency.

Practical actions recommended by SFP to seafood buyers

Seafood buyers can support best practices in fisheries to conserve food webs with the following practical actions:

1. ***Prioritize source fisheries that have the most urgent need to address fishing impacts on food webs as part of EBFM.*** Likely candidates are fisheries targeting apex predators, keystone species, highly sensitive species, and species that make up a high proportion of the ecosystem's biomass or are highly connected in the food web. Also look for evidence of mean trophic level shifts that could indicate fishing down or through the food web.

   To determine whether managers are already addressing this issue, a number of questions should be investigated. Are managers using any sort of multispecies models? Have they created a model of the food web/ecosystem or a dynamic model that allows them to test the potential effects of management measures? Have managers set any precautionary management measures for harvest of low trophic level species? Are there any environmental target and ecological indicators that consider the food web and ecosystem?

2. ***Where a significant negative impact of fishing on a food web is suspected and EBFM is not being applied, encourage fishery regulators to consider precautionary management measures.*** Precautionary management is intended to avoid or mitigate undesirable outcomes such as reduced ecosystem function. Lack of data or scientific studies is not necessarily a reason for precluding precautionary action. Management measures can be put into place despite having robust data sets, complex modeling, and environmental targets. Examples of precautionary management measures include setting higher biomass targets for species important to the food web, reducing fishing effort on low trophic level species, and managing for the sustainability of the most sensitive species in an ecosystem.

   Where precautionary management is needed, major buyers can communicate a request directly to the regulators (e.g., by letter, email) or down through the supply chain to a company that will communicate directly with the regulators.

3. ***Encourage fishery regulators to identify ecological indicators and set environmental targets where they do not already exist.*** Every ecosystem has a set of indicators that can be used to measure the overall health of that ecosystem. Scientists can identify those indicators using existing knowledge and data or through new studies and set targets for each. Management regulations can be created to achieve or maintain ecosystem health based on those targets.

   Where indicators and targets are needed, major buyers can communicate a request directly to the regulators (e.g., by letter, email) or down through the supply chain to a company that will communicate directly with the regulators.

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