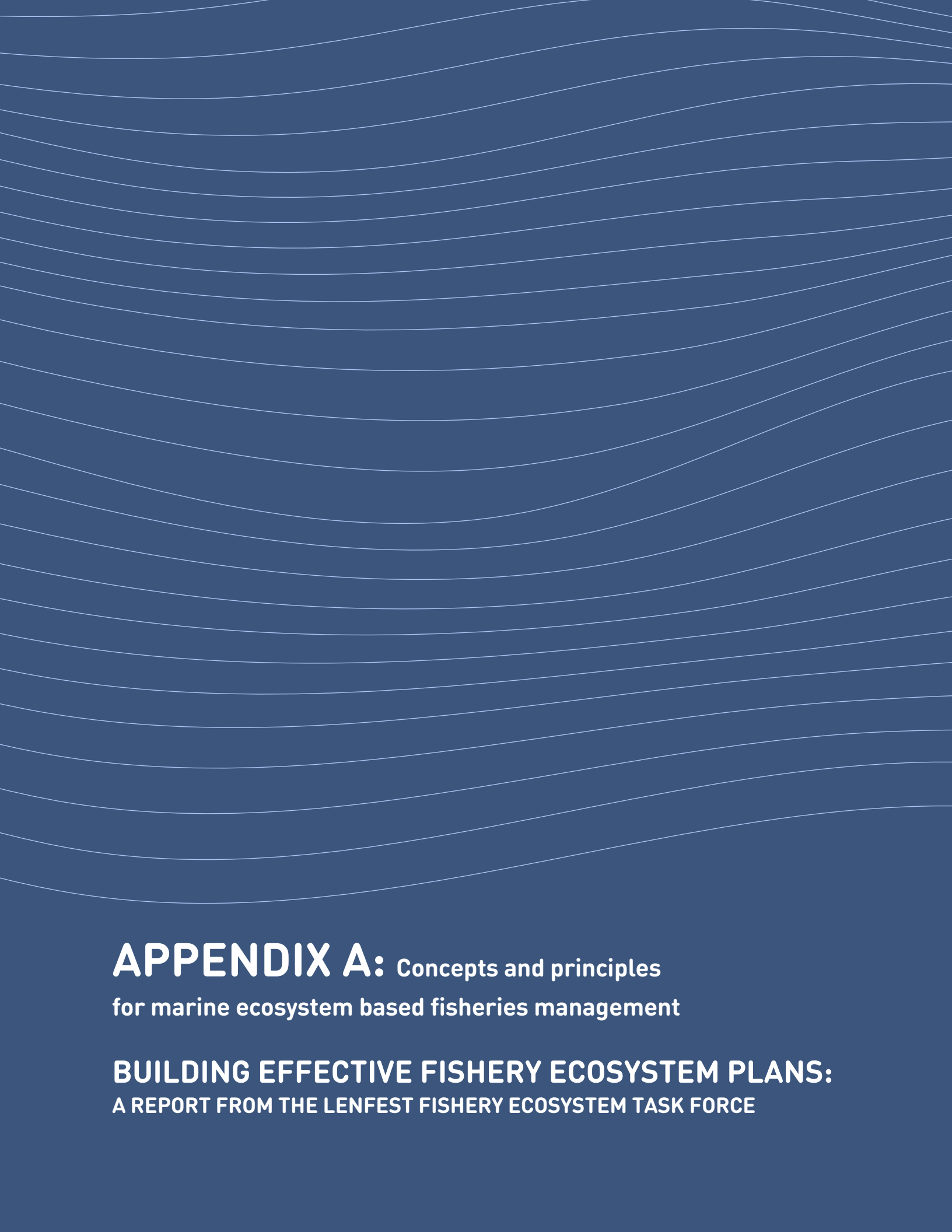




APPENDIX A: Concepts and principles for marine ecosystem based fisheries management

BUILDING EFFECTIVE FISHERY ECOSYSTEM PLANS:
A REPORT FROM THE LENFEST FISHERY ECOSYSTEM TASK FORCE

Appendix A

CONCEPTS AND PRINCIPLES FOR MARINE ECOSYSTEM BASED FISHERIES MANAGEMENT

Here we articulate the Task Force vision of ecosystem-based fisheries management (EBFM) that underlies and guides our recommendations for fishery ecosystem plans. Many distinct definitions of ecosystem-based management – and EBFM – exist (Grumbine 1994, Larkin 1996, Pikitch et al. 2004, McLeod et al. 2005), so we offer a synthetic definition that encapsulates several common themes among them. That is, we define EBFM as a holistic, place-based framework that seeks to sustain fisheries and other services that humans want and need by maintaining healthy, productive, and resilient fishery systems. (Larkin 1996, Garcia et al. 2003, Pikitch et al. 2004, McLeod et al. 2005, Link 2010, Fogarty 2014). This contrasts with the single-species management framework that is more narrowly focused on the direct consequences of management actions on targeted stocks while largely ignoring the systems (both natural and human) within which those stocks are imbedded.

A more specific vision of EBFM emerges by summarizing commonly-stated principles and concepts. When reviewing the abundant literature on this topic, we found a strong focus on the dynamics, structure, and sustainability of natural systems, with less consideration of the structure and dynamics of human systems, linkages between ecological and human systems and the need for management to meet ecological, economic and social objectives (Urquhart et al. 2011, Halpern et al. 2013, Klain et al. 2014, Anderson et al. 2015, Hilborn et al. 2015) – the triple bottom line (Anderson et al. 2015). We therefore reviewed common principles for EBFM, and updated some as needed to produce a list that includes both ecological and human attributes. Our intent was to identify the principles that have received the most attention (e.g., Long et al. 2015) and are most relevant for fisheries management rather than to form a comprehensive list of EBFM topics.

Fisheries are Systems

Fundamental to ecosystem-based management is the conceptualization of fisheries as systems that consist of linked biophysical and human subsystems with interacting ecological, economic, social, and cultural components (Charles 2001, 2014). Within this context, we synthesize the principles relevant to fisheries as systems.

A system is comprised of its components (e.g. targeted fish stock, people employed by fishing), and the linkages among them. A linkage simply refers to the case when the status or action of one component influences another component. Because fishery systems typically contain many linked components, management actions can produce unintended indirect effects if these linkages are not accounted for (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Bianchi et al. 2008). We describe some of the key types of linkages in natural, human, and cross-system linkages here.

Within the ecological systems, there are important linkages between biophysical processes (e.g. oceanography and geology) with biological processes affecting organisms such as reproduction, growth, and mortality. Fishery systems are also affected by ecological linkages among these organisms – species interactions that range from predation and competition to parasitism and cooperative hunting – that influence individual survival and biological diversity (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Bianchi et al. 2008).

Human systems consist of diverse linkages among individuals directly engaged in fishing (harvesters), the post-harvest system (processors, distribution, and markets), and the larger communities in which these individuals belong. Critically, harvesters are often diverse, consisting of subsistence, recreational and commercial sectors, and actions of one group can indirectly affect another, and these sectors may have distinct objectives for management.

Human systems are strongly and directly linked to natural systems through targeted species – those sought for food or for livelihood – and indirectly to non-targeted species with which targeted species interact. Human systems can also alter the habitats that species depend upon. Critically, economic, cultural and ethical aspects of human systems govern the demand for seafood or livelihoods and thereby dictate the intensity and nature of fishing activities (Long et al. 2015). The status of natural systems directly affects livelihoods of fishery dependent communities and is sometimes critical for maintaining cultural traditions and the meanings the individuals derive from them.

Distinct sectors within human systems also interact whereby activities by one sector affects other sectors – for example, fisheries compete with transportation, energy, and recreational use of water bodies (Halpern et al. 2008). This complexity, especially in coastal and estuarine systems creates significant challenges for management and governance.

Below we review properties of fisheries systems that are relevant for EBFM.

Principles of EBFM: Key attributes of fishery systems

Systems are dynamic

Systems are constantly changing in response to internal and external drivers (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Bianchi et al. 2008, Long et al. 2015). An internal driver might be the recovery of a large, apex predator which results in reductions of lower trophic level species. An external driver might be distant markets that dictate prices for landed fish. These changes can happen over short time scales (seasonal or annual) or over longer time scales (decades). Changes can occur quickly, for instance when climatological conditions shift into distinct regimes.

Diversity provides benefits

Diversity is considered a hedge against uncertainty and a means of enhancing ability of systems to withstand external shocks (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Francis et al. 2007, Bianchi et al. 2008, Long et al. 2015). There are many dimensions of diversity relevant for EBFM. Biological diversity incorporates genetic, taxonomic, functional, and ecosystem characteristics of populations and communities. Human diversity incorporates cultural, ethnic, geographic, and technological characteristics of communities engaged in fisheries. For example, diversity in fishing opportunities can, in some cases, foster the maintenance of livelihoods in the face of environmental and economic variability (Kasperski and Holland 2013).

Resources are limited

There are limits to the rate at which natural systems can provide benefits to humans (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003). This is already appreciated in single species management, where the maximum long-term sustainable catch is often explicitly estimated for those stocks of particular economic importance. At a systems level, there is a limit on the total rate of removals from an ecosystem that is sustainable. This rate will depend on the inherent productivity of the system, the trophic level of targeted species, and the diversity of species harvested. In most cases, the system-level maximum sustainable yield is less than the sum of individual species maximum sustainable yields largely because the methods used to estimate species maximum yields do not consider the interactions among species (Link 2010).

Systems are scaled in time and space

System dynamics are governed by multiple processes that operate at vastly different scales in time and space (Ecosystems Principles Advisory Panel 1999, Long et al. 2015). The scaling of social, ecological, and institutional processes is critical for effective management of fishery systems. In particular, cross-scale interactions (linkages

between processes that operate at small spatial or short temporal scales with those that operate on broader spatial or time scales) are common and can confound prediction and management if not explicitly identified (Ecosystems Principles Advisory Panel 1999). This is because forecasting response of systems with cross-scale dynamics is generally not possible when the system is viewed at only a single scale (Peters et al. 2004). Moreover, lack of formal consideration of cross-scale interactions – particularly between social and ecological systems – often lead to ineffective management decisions (Cash et al. 2006, Peters et al. 2007)

System boundaries are open

Marine ecosystems are porous and boundaries are poorly defined; yet, exchanges across system boundaries can be important drivers of change (Ecosystems Principles Advisory Panel 1999, Long et al. 2015). Open boundaries can contribute to or threaten the stability of an ecosystem. Variable boundary conditions can promote or limit connectivity and thus impact dispersal and migrations of marine organisms and fisheries dependent on them.

Ecological and human system boundaries can be different

Natural, human, and governance subsystems often have different boundaries and geographic scope, which can have management implications. The spatial scope of management needs to be clearly defined (Arkema et al. 2006), as does the extent to which the natural and human systems are influenced by external factors, and the spatial scope of these factors (e.g., markets in one part of the world driving demand for fish products from another part of the world).

Systems have tipping points

System change can be rapid and irreversible, so it is important to know what components of systems confer resilience and maintain those elements (Ecosystems Principles Advisory Panel 1999, Francis et al. 2007, Long et al. 2015). Once a tipping point has been crossed, it must be recognized and appropriate actions must be taken to avoid collapse of fisheries and biological communities that support them. Failure to recognize tipping points makes restoration difficult. Large-scale climatic change is one cause of rapid change that may be followed by sustained conditions for decades. Inertia in the social components of fishery systems can cause lags in the response to ecological or social tipping points.

Principles of EBFM: Key attributes for EBFM implementation

Now that we have a clear idea of the concept and principles of fisheries as systems, we briefly list below a series of guiding principles for implementing EBFM, with specific focus for how scientific information should be used in an EBFM framework. We note here that many of these are not unique to EBFM; that is, they are important components of any successful management system. But rather, these elements are a necessary part of EBFM.

Integrated management is needed

Regional fisheries organizations generally have authority to regulate activities in one ocean use sector (fishing), yet regulatory decisions need to be made in the context of other ocean use sectors (energy, tourism and recreation, shipping, etc.) and in some cases terrestrial land use sectors (e.g. coastal zone development, agriculture). Management plans that presume status quo conditions may not meet their objectives if changes in other sectors alter fishing opportunities or alter population or ecosystem productivity. The cumulative effects of multiple ocean uses on fisheries may be additive, synergistic (the cumulative effect is greater than the sum of individual effects), or antagonistic (the cumulative effect is less than the sum of individual effects) (Thia-Eng 1993, McLeod et al. 2005, Long et al. 2015)

Scientific advice for EBFM is interdisciplinary

EBFM requires integration of several scientific disciplines, such as oceanography, geology, population biology, community food web ecology, economics, anthropology, sociology, and political science (Bianchi et al. 2008, Long et al. 2015).

EBFM requires broad stakeholder involvement

It is important for all stakeholders, including marginalized groups, to be engaged in the decision making process. In an EBFM context, the stakeholder base is typically much broader than in single species management. This engagement is particularly important for mapping trade-offs and for understanding system structure. Broad stakeholder engagement often leads to expanded sets of management alternatives (Bianchi et al. 2008, Daw et al. 2015, Long et al. 2015), and is critical for devising decision rules (Fogarty 2014).

Management decisions must be made under uncertainty

Our ability to predict the behaviour of complex systems is limited, so decisions need to be made in a structured way that acknowledges this uncertainty (Garcia 1994, Ecosystems Principles Advisory Panel 1999, Long et al. 2015, Hall and Mainprice 2004). There are three related concepts that apply to management under uncertainty

Risk-Based Frameworks: Risk-based frameworks identify outcomes that management seeks to avoid, and then judges both the likelihood that management objectives will be met and the effect of uncertainty on objectives (Fletcher 2014).

Precautionary Management: The precautionary approach to management means avoiding actions that have a high risk of causing serious or irreversible harm. Often, the precautionary approach has been associated with placing the burden of proof on individuals that seek to engage in fishing activities to demonstrate that doing so will not cause unacceptable ecological harm (Dayton 1998, Gerrodette et al. 2002). A broad view of the precautionary approach is needed that balances risk across management objectives.

Adaptive management

By evaluating the response of systems to management actions, one can gain understanding about how the system works, thereby reducing uncertainty (Ecosystems Principles Advisory Panel 1999, Garcia et al. 2003, Hall and Mainprize 2004, Long et al. 2015). Consequences of management actions can reveal system linkages that were not previously understood, or their importance under-estimated (Dayton et al. 2002). Although “active” adaptive management that usually requires experimentation is often not feasible (Walters 1997), responsible “passive” adaptive management can be undertaken for most management actions.

EBFM requires ecosystem monitoring, indicators, and reference points

Effective monitoring of fisheries systems is essential to gauge the success of management actions, to identify unintended indirect effects of decisions, to identify changes in the ecosystem that will affect the performance of management systems, and to enable adaptive management. Monitoring under EBFM will likely involve system level indicators and establishing system reference points (Link 2002, Garcia et al. 2003, Hall and Mainprize 2004, Arkema et al. 2006, Bianchi et al. 2008, Tallis et al. 2010). Indicators may track the status of individual components of fishery systems, either because they are directly related to management objectives or because they are a useful proxy of valued components of fishery systems. Indicators may also track the status of the system-level properties relevant for its structure and functioning. System-level reference points indicate target or limits and guide the application of management interventions

Ecosystem decision rules are needed

Just as in single-species management (e.g., where harvest control rules are used to set quota based on estimated stock abundance), EBFM will likely require decision rules that guide tactical decisions based on system state. The adoption of these decision

rules will require stakeholder participation to identify system goals, and an analysis of alternative decision rules to identify those that are most likely to meet EBFM management objectives (Hall and Mainprize 2004, Bianchi et al. 2008). Decision rules should be as simple, transparent, and easily understood as is possible (Fogarty 2014).

Trade-offs need to be identified

Because of the connections among and within biophysical and social systems, decisions made to favor some activities (e.g. particular fishing sectors) may cause harm in other sectors. Traditional management often makes decisions without consideration of these trade-offs (Link 2010). Lack of attention doesn't render a fundamental trade-off non-existent. Science can provide information about trade-offs, but usually there is no single win-win management alternative that will maximize benefits across all management objectives (Halpern et al. 2013). Broad stakeholder involvement is needed to identify trade-offs because some trade-offs are hidden from policy makers and scientists tasked with giving advice (Fogarty 2014, Daw et al. 2015). Broader trade-offs with other marine sectors of commerce and use also are implied in comprehensive EBFM, particularly in estuarine and coastal fisheries. Conflicts with transportation, ports, energy industries, and agriculture, for example, will arise, and trade-offs may need to be negotiated.

Protect and restore key components

In many ecological and social systems, a handful of components are responsible for providing benefits from fisheries and thereby support management objectives. Identifying these key components, and then ensuring that actions do not pose risk of irreversible harm to these components, will be an important component of EBFM (Francis et al. 2007). These key components might be ecological keystone species, cultural keystone species, diversity in fishing opportunities, or critical habitats for valued stocks.

References

- Anderson, J. L., C. M. Anderson, J. Chu, J. Meredith, F. Asche, G. Sylvia, M. D. Smith, D. Anggraeni, R. Arthur, A. Guttormsen, et al. 2015. The fishery performance indicators: a management tool for triple bottom line outcomes. PLoS ONE 10:e0122809.
- Arkema, K. K., S. C. Abramson, and B. M. Dewsbury. 2006. Marine ecosystem-based management: from characterization to implementation. *Frontiers in Ecology and the Environment* 4:525-532.
- Bianchi, G., P. Sandberg, H. R. Skjoldal, and K. Thorarinsson. 2008. The Bergen conference on implementing the ecosystem approach to fisheries (Bergen

- Norway, 26-28, September 2006): Summary and main conclusions. Pages 1-19 in G. Bianchi and H. R. Skjoldal, editors. *The Ecosystem Approach to Fisheries*. FAO, Rome.
- Cash, D. W., W. N. Adger, F. Berkes, P. Garden, L. L., P. Olsson, L. Pritchard, and O. Young. 2006. Scale and cross-scale dynamics: governance and information in a multi-level world. *Ecology and Society* 11:8.
- Charles, A. 2001. *Sustainable Fishery Systems*. Blackwell Science, Oxford.
- Charles, A. 2014. Human dimensions in marine ecosystem-based management. Pages 57-75 in M. Fogarty and J. J. McCarthy, editors. *The Sea*. Harvard University Press, Cambridge, MA.
- Daw, T. M., S. Coulthard, W. W. Cheung, K. Brown, C. Abunge, D. Galafassi, G. D. Peterson, T. R. McClanahan, J. O. Omukoto, and L. Munyi. 2015. Evaluating taboo trade-offs in ecosystems services and human well-being. *Proc Natl Acad Sci U S A* 112:6949-6954.
- Dayton, P. K. 1998. Reversal of the burden of proof in fisheries management. *Science* 279:821-822.
- Dayton, P. K., S. Thrush, and F. C. Coleman. 2002. *The Ecological Effects of Fishing in Marine Ecosystems of the United States*. The Pew Oceans Commission, Arlington, VA.
- Ecosystems Principles Advisory Panel. 1999. *Ecosystem-based fishery management*. National Marine Fisheries Service.
- Fletcher, W. J. 2014. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. *ICES Journal of Marine Science* 72:1043-1056.
- Fogarty, M. J. 2014. The art of ecosystem-based fishery management. *Canadian Journal of Fisheries and Aquatic Sciences* 71:479-490.
- Francis, R. C., M. A. Hixon, M. E. Clarke, S. A. Murawski, and S. Ralston. 2007. Ten Commandments for Ecosystem-Based Fisheries Scientists. *Fisheries* 32:217-233.
- Garcia, S. M., A. Zerbi, C. Aliaume, T. Do Chi, and G. Lasserre. 2003. *The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook*. Food and Agriculture Organization, Rome.
- Garcia, S. M. 1994. The precautionary principle: Its implications in capture fisheries management. *Ocean & Coastal Management* 22:99-125.
- Gerrodette, T., P. K. Dayton, S. Macinko, and M. J. Fogarty. 2002. Precautionary management of marine fisheries: moving beyond burden of proof. *Bulletin of Marine Science* 70:657-668.
- Grumbine, R. E. 1994. What is ecosystem management? *Conservation Biology* 8:27-38.
- Hall, S. J. and B. Mainprize. 2004. Towards Ecosystem-based fisheries management. *Fish and Fisheries* 5:1-20.
- Halpern, B. S., C. Klein, J., C. J. Brown, M. Beger, H. S. Grantham, S. Mangubhai, M. Ruckelshaus, V. J. Tullock, M. Watts, C. White, et al. 2013. Achieving the triple

- bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. *Proceedings of the National Academy of Science of the United States of America* 110:6229-6234.
- Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, et al. 2008. A global map of human impact on marine ecosystems. *Science* 319:948-952.
- Hilborn, R., E. A. Fulton, B. S. Green, K. Hartmann, S. R. Tracey, and R. A. Watson. 2015. When is a fishery sustainable? *Canadian Journal of Fisheries and Aquatic Sciences*:1-9.
- Kasperski, S. and D. S. Holland. 2013. Income diversification and risk for fishermen. *Proceedings of the National Academy of Science of the United States of America* 110:2076-2081.
- Klain, S. C., R. Beveridge, and N. J. Bennett. 2014. Ecologically sustainable but unjust? Negotiating equity and authority in common-pool marine resource management. *Ecology and Society* 19.
- Larkin, P. A. 1996. Concepts and issues in marine ecosystem management. *Reviews in Fish Biology and Fisheries* 6:139-164.
- Link, J. 2002. Ecological considerations in fisheries management: When does it matter? *Fisheries* 27:10-17.
- Link, J. S. 2010. *Ecosystem-based fisheries management: confronting tradeoffs*. Cambridge University Press, Cambridge.
- Long, R. D., A. Charles, and R. L. Stephenson. 2015. Key principles of marine ecosystem-based management. *Marine Policy* 57:53-60.
- McLeod, K. L., J. Lubchenco, S. R. Palumbi, and A. A. Rosenberg. 2005. *Scientific Consensus Statement on Marine Ecosystem-Based Management*,.
- Peters, D. P., R. A. Pielke, Sr., B. T. Bestelmeyer, C. D. Allen, S. Munson-McGee, and K. M. Havstad. 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. *Proc Natl Acad Sci U S A* 101:15130-15135.
- Peters, D. P. C., B. T. Bestelmeyer, and M. G. Turner. 2007. Cross-scale interactions and changing pattern-process relationships: Consequences for system dynamics. *Ecosystems* 10:790-796.
- Pikitch, E. K., C. Santora, E. A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, et al. 2004. Ecosystem-based fishery management. *Science* 305:346-347.
- Tallis, H., P. S. Levin, M. Ruckelshaus, S. E. Lester, K. L. McLeod, D. L. Fluharty, and B. S. Halpern. 2010. The many faces of ecosystem-based management: Making the process work today in real places. *Marine Policy* 34:340-348.
- Thia-Eng, C. 1993. Essential elements of integrated coastal zone management. *Ocean & Coastal Management* 21:81-108.
- Urquhart, J., T. Acott, M. Reed, and P. Courtney. 2011. Setting an agenda for social science research in fisheries policy in Northern Europe. *Fisheries Research* 108:240-247.

Walters, c. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1:[online] URL:
<http://www.consecol.org/vol1/iss2/art1/>.