Alignment of Ocean Tipping Points Science with Stock- and Ecosystem-Based Fisheries Management under the Magnuson-Stevens Act

Table of Contents

Purpose Statement

This document briefly summarizes key statutory and regulatory requirements for managing fisheries under the Magnuson-Stevens Act and identifies points in the regulatory process where tipping points science may be most useful to managers and improving existing practice. The "Summary for Managers" describes these high level insertion points for tipping points science. A more comprehensive analysis of fisheries management under the Magnuson-Stevens Act follows.

This document is designed for use primarily by fishery managers and agency scientists interested in using tipping points science in their work. However, we have attempted to make this document accessible to a broader audience by including background information on the statutory and regulatory requirements of the Magnuson-Stevens Act.

This document regularly refers to tipping points scientific strategies, which are not explained in detail in this document. For information on these strategies, please refer to the Ocean Tipping Points Guide.

Summary for Managers

The Ocean Tipping Points strategies are designed to facilitate the establishment of regulatory limits that are directly linked to ecological thresholds, and complementary management actions. Thus, they can help identify ecological thresholds of concern under the Magnuson-Stevens Act, explore social preferences and acceptable levels of risk, and designate regulatory limits and management approaches to meet those limits. Ocean Tipping Points strategies can also expand the integration of social and cultural concerns and impacts into management decisions. While the essential considerations outlined in this project are not new to fisheries management, the systematic process and guidance for identifying and managing ecological thresholds of concern provided by the Ocean Tipping Points Guide can improve the use of ecological thresholds in fisheries management decisions.

The Ocean Tipping Points project team has identified that tipping points science is well-suited to assist fishery managers to:

- Incorporate ecosystem thresholds in fisheries stock assessments – The tipping points strategy for characterizing tipping points and their drivers can assist managers in fisheries management measures—such as annual catch limits—that are directly linked to ecological thresholds.
- Consider other human impacts in OY determination – The tipping points strategy for characterizing tipping points and their drivers can assist managers in identifying how non-fishing threats effect a managed species or ecosystem and incorporate those drivers in management decisions.
- Incorporate social and cultural concerns into management decisions – The tipping points strategy for characterizing social preferences and risk tolerance can assist managers in making decisions that are broadly aligned with public opinion and priorities.
- Explore novel approaches for replacing or supplementing single-species management approaches with ecosystem-based fisheries management – The suite of tipping points strategies is broadly in line with emerging trends towards ecosystem-based fisheries

management. The tipping points guide may be effective in providing a roadmap for future ecosystem initiatives under the Magnuson-Stevens Act.

While the science and application of tipping points are still evolving, a growing number of examples reveal successful application of tipping points science in action. For real-world examples, see our case study write-ups:

- Coral Reefs in Discovery Bay, Jamaica
- Sea Urchins in the Gulf of Maine

For more detail, continue to the full analysis on page 4.

Introduction

The Magnuson-Stevens Fishery Conservation and Management Act (MSA or Magnuson-Stevens Act) and its accompanying regulatory regime are the primary laws governing the management of fisheries in U.S. federal waters.[1] The MSA requires the sustainable use of fishery resources, providing protections for many components of ocean ecosystems. With regards to managing fished stocks, the MSA's "national standard one" requires management measures that prevent overfishing and achieve optimum yield (OY) for each fishery.[2] The term optimum yield refers to the amount of fish that provides the greatest overall benefit to the Nation, accounting for food production, recreational opportunities, and protection of marine ecosystems but never exceeding sustainable levels.[3] More specifically, OY is based on maximum sustainable yield (MSY)—the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions, fishery technological characteristics (e.g., gear selectivity), and the distribution of catch among fleets[4]—"as reduced by any relevant economic, social, or ecological factor."[5] The MSA's definitions of both MSY and OY contemplate consideration of both species-specific and ecosystem health thresholds.

A Note on NEPA

Many U.S. federal fisheries management decisions, such as the creation of fishery management plans and implementation of regulations, require environmental impact assessments and thus trigger action under the National Environmental Policy Act (NEPA). NEPA actions provide additional opportunities to incorporate tipping points science into specific process-based requirements to improve management success.

Please refer to our analysis on the National Environmental Policy Act (NEPA) for an exploration of the development and implementation of environmental and cumulative impact analyses under NEPA, identifying ocean tipping point science "integration points" along the way.

Current management guidance (NOAA's National Standards Guidelines) calls for MSY and OY to provide the basis for both status determination criteria—criteria that define when a stock is overfished or subject to overfishing—and required catch limits for each fishery.[6] In other words they are directly linked to the legally harvestable portion of fishery resources and the regulatory thresholds beyond which rebuilding plans are required and accountability measures (i.e., consequences) are triggered. In this way, the regulatory system calls for incorporation of social, economic, and ecosystem considerations. The ongoing push for ecosystem-based fisheries management provides additional motivation for identifying ecosystem tipping points and linking them to management decisions. While the Magnuson-Stevens Act currently has no ecosystem management mandate, agency practice and best available science are steadily progressing, enabling a more holistic ecosystem approach to management.

[1] *See generally* 16 U.S.C. § 1801; 50 C.F.R. § 600.5.

[2] 16 U.S.C. § 1851(a)(1).

[3] 16 U.S.C. § 1802(33).

[4] 50 C.F.R. § 600.310(e)(1)(i)(A).

[5] 16 U.S.C. § 1802(33).

[6] 50 C.F.R. §§ 600.310(e)(2)(i)(A) & 600.310(f)(5)(i).

The following text explores the applicability of Ocean Tipping Points (OTP) concepts (*See Table 1*) to the designation of stock or stock complex harvest limits under the MSA and the push for ecosystem-based fisheries management. This crosswalk concludes that while the essential considerations outlined by the OTP project are not new to managers, the systematic process and guidance provided for identifying and managing thresholds of concern can improve the incorporation of thresholds into fishery management decisions.

Table 1: OTP Concepts
Characterize thresholds in the system a. Define thresholds of concern b. Identify drivers of thresholds and characterize the shapes of relationships between drivers and ecosystem components
Define objectives – where do you want to be relative to thresholds? a. Characterize social preferences with respect to ecosystem regimes b. Analyze risk of crossing a threshold and characterize risk tolerance to the changes that could result
Design indicators and targets a. Identify leading indicators that signal the approach of a threshold b. Set targets and limits based on known thresholds, social preferences, and risk analysis
Evaluate scenarios and select a course of action a. Develop future management scenarios b. Evaluate management alternatives using appropriate tools and take action
Monitor the ecosystem state and response to management intervention a. Adaptively manage – evaluate results of management action and assessment of ecosystem state from monitoring data and decide whether to adjust course b. Refine models and assumptions based on new knowledge

Designation of Stock or Stock Complex Harvest Limits

Regulations – NMFS Guidance for National Standard One

NMFS regulations provide advisory guidelines for the setting of MSY and OY, status determination criteria, and annual catch limits necessary to achieve OY and prevent overfishing. Although these advisory guidelines do not have the force of law, the regional Councils follow them closely in practice.

Maximum Sustainable Yield (MSY) – Species-specific productivity threshold

Each FMP must include an estimate of MSY for the stock based on best available science.[7] MSY is defined as the largest long-term average catch that can be taken from a

[7] 50 C.F.R. § 600.310(e)(1).

stock under prevailing conditions.[8] MSY is frequently referred to in the context of the biomass necessary to maintain MSY or the fishing mortality rate that would result in MSY. For many managed fisheries, both biomass and fishing levels required to maintain MSY are identified. Regulations facilitate the incorporation of environmental and ecological conditions into the estimation of MSY to the extent they impact the population health of the assessed stock, but this rarely occurs in practice. In the event that scientific information does not enable an estimation of MSY, proxies based on other measures of reproductive potential are used.[9]

- Estimating MSY requires NMFS to understand a given species' population growth rate under existing conditions. At this stage in the regulatory process the **threshold of concern** is predefined: the exploitation rate beyond which productivity of the stock is compromised.
- The statutory scheme also defines the **social preference** with respect to this threshold as ensuring continued productivity of the stock in lieu of short-term catch benefits.

<u>Status Determination Criteria (SDC) – Species-specific biomass and catch thresholds</u>

Each FMP must set status determination criteria, or the measurable and objective factors that are used to determine whether overfishing is occurring or the stock is overfished.[10] Overfishing criteria are generally expressed as a level of fishing mortality or catch, while overfished criteria are generally expressed as a level of biomass. Overfishing criteria include overfishing limit (OFL) (i.e., a number or weight of catch) and maximum fishing mortality threshold (i.e., a level of fishing mortality) that, if exceeded, result in overfishing.[11] The overfished criteria is a minimum stock size threshold expressed as a level of biomass or other measure of reproductive potential.[12] These SDC are ideally based on MSY. However, when data to specify SDC based on MSY is unavailable, managers may use MSY proxies based on other data, including average catch, fish density surveys, length/weight frequencies, or other methods.[13] If the estimated size of the stock falls below this level, the stock is considered overfished.

- The overfished criteria represent a regulatory **limit**: rebuilding plans must be created if overfished criteria are breached. Overfished criteria also represent a **rebuilding indicator** following a reduction in effort that occurs after the stock initially crosses the regulatory limit.
- Arguably, the overfishing criteria are **leading indicators** that signal the approach of the overfished criteria threshold limit.

[8] 50 C.F.R. § 600.310(e)(1)(i)(A).
[9] 50 C.F.R. §600.310(e)(1)(v)(B).
[10] 50 C.F.R. § 600.310(e)(2)(i)(A).
[11] 50 C.F.R. § 600.310(e)(2)(ii)(A).
[12] 50 C.F.R. § 600.310(e)(2)(ii)(B).
[13] 50 C.F.R. § 600.310(e)(2)(ii).

Optimum Yield (OY) – Long-term harvest target that incorporates social, economic, and ecological factors

Each FMP must define the OY of the fishery—the yield from a fishery that provides the greatest overall benefit to the Nation—in terms of numbers or weight of fish.[14] OY gives managers a mechanism to consider protection of marine ecosystems and social and economic concerns, thereby preventing consideration of stock health in a vacuum without accounting for linked social, biological, physical, and/or chemical components in the system. NMFS guidance provides a non-exclusive list of important social,[15] economic,[16] and ecological[17] considerations that should receive attention when setting OY. In addition to these required considerations, the MSA's national standard 8 also mandates that conservation and management measures take into account best available economic and social data and the importance of fishery resources to fishing communities.[18] Federal FMPs contain a broad range of qualitative and quantitative definitions for OY. While some explicitly mention the economic, environment, and social factors considered, others do not.

- Social, economic, and ecological **thresholds of concern should be identified and drivers characterized**. In practice, these considerations can be incorporated directly into stock assessments or can influence the setting of annual catch limits.
- The complex interactions and difficulty in direct observation of marine ecosystems makes identification of quantitative ecosystem thresholds notoriously difficult. As a result, most FMPs identify qualitative ecosystem thresholds (e.g., ecosystem collapse, trophic cascade) and explore fishery related drivers of these thresholds in very general terms. Limits are placed on harvest based on these qualitative concerns, usually in terms of a percent reduction in harvest to fulfill ecosystem needs.[19]

[14] 50 C.F.R. § 600.310(e)(3)(i)(A).

[15] Social factors include enjoyment gained from recreational fishing, avoidance of gear conflicts and resulting disputes, preservation of a way of life for fishermen and their families, and dependence of local communities on a fishery. Consideration may be given to social indicators or thresholds such as unemployment rates and percent of population below the poverty level. 50 C.F.R. § 600.310(e)(3)(iii)(B)(1).

[16] Economic factors include prudent consideration of the risk of overharvesting when a stock's size or reproductive potential is uncertain, satisfaction of consumer and recreational needs, and encouragement of domestic and export markets for U.S. harvested fish. Consideration may be given to economic indicators or thresholds such as the value of fisheries, the level of capitalization, decreases or increases in catch per unit of effort, alternate employment opportunities, and economic contribution to fishing communities, coastal areas, affected states, and the nation. 50 C.F.R. § 600.310(e)(3)(iii)(B)(2).

[17] Ecological factors include impacts on ecosystem component species, forage fish stocks, other fisheries, predator-prey or competitive interactions, marine mammals, threatened or endangered species, and birds. Consideration may be given to ecological indicators or thresholds such as biomass of forage fish and effects of pollutants on habitat and stocks. 50 C.F.R. § 600.310(e)(3)(iii)(B)(3).

[18] 16 U.S.C. § 1851(a)(8); 50 C.F.R. § 600.345.

[19] For example, managers frequently use the recommended default target control rule of 75% of Fmsy outlined in NOAA Technical Memoranda to define OY. V.R. Restrepo et al., National Marine Fisheries Service, Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act (1998). For an implementation of this recommendation, *see* South Atlantic Fishery Management Council, Snapper Grouper Amendment 15a, at 4-4–4-5 (Dec. 2007) *available at* http://www.safmc.net/Library/pdf/SGAmend15A_FEIS.pdf. Conversely, forage species that are relied on more heavily by the ecosystem may have a higher reduction in OY and a lower percentage of biomass available for

- Social considerations are likewise difficult to quantify and are frequently expressed in general terms, when included in management documents. Economic considerations, such as substantial reductions in effort and cost of fishing that coincide with minimal reductions in catch, are much easier to identify and quantify. Generally speaking, economic and social thresholds are avoided by providing regulatory stability in the form of minimum and maximum harvest levels that constrain growth or shrinkage of fishing fleets. In Alaska and the Pacific Northwest, tribal treaty rights are also considered.[20] Despite the MSA's national standard 8 mandate, sociocultural considerations are rarely addressed beyond the direct impacts of changes in policy on the commercial fishing community and tribal rights.
- OY provides an explicit mechanism through which species-specific targets and limits based on thresholds can be reduced to accommodate ecosystem-level and socioeconomic thresholds. **OY is a long-term management target** based on threshold concerns.

Annual Catch Limits (ACLs) – Annual regulatory limits

Each FMP must establish a management strategy, including an annual catch limit, that prevents overfishing and ensures achievement of OY.[21] To establish annual catch limits, the acceptable biological catch must be specified.[22] Acceptable biological catch is a level of annual catch that accounts for uncertainty in the estimation of the overfishing limit, maximum sustainable yield, or stock biomass and incorporates an acceptable level of risk to overfishing.[23] Annual catch limits must not be greater than the designated acceptable biological catch.[24] Recent revisions to NMFS guidance attempt to clarify the relationship between OY and the ACL framework. The guidance recognizes that OY considerations can be incorporated into annual catch limits and that when OY is expressed as an annual catch, it cannot exceed the annual catch limit.[25] This guidance remains vague and discretionary, and as a result, no uniform practice for incorporating the OY considerations (e.g., ecosystem concerns, socioeconomic concerns) into the ACL framework exists. For some fisheries, acceptable biological catch and annual catch limits are calculated prior to OY and form the basis for OY in the fishery; in others OY is calculated from MSY and informs the setting of annual catch limits.[26]

harvest in response to qualitative OY (i.e., social, economic, ecological) concerns. *See e.g.*, Pacific Fishery Management Council, Coastal Pelagic Species Fishery Management Plan: as Amended Through Amendment 15, at 7, 39 (Feb. 2016) *available at* http://www.pcouncil.org/wp-content/uploads/2016/05/CPS_FMP_as_Amended_thru_A15.pdf.

[20] *See e.g.*, Pacific Fishery Management Council, Pacific Coast Salmon Fishery Management Plan 58 (Mar. 2016) *available at* http://www.pcouncil.org/wp-content/uploads/2016/03/FMP-through-A-19_Final.pdf.

[21] 50 C.F.R. § 600.310(b)(1)(iii).

[22] 50 C.F.R. § 600.310(f)(3).

[23] 50 C.F.R. § 600.310(f)(1)(ii).

[24] 50 C.F.R. § 600.310(f)(4)(i).

[25] 50 C.F.R. § 600.310(f)(4)(iv).

[26] Fisheries Leadership and Sustainability Forum, West Coast Forum 2012: National Standard 1 & Optimum Yield Summary and Discussion Themes 3 (Sept. 2012).

- Annual catch limits are **regulatory limits that can be based on both species-specific and ecosystem thresholds, as well as risk and uncertainty.**

Annual catch targets (ACTs) – Annual regulatory targets

Annual catch targets are optional management mechanisms that can be used to limit catch below the annual catch limit, accounting for management uncertainty or other factors.[27] Annual catch targets are the **annual management target of the fishery**, as opposed to its limit, and so exceeding the annual catch target generally does not lead to closure in the fishery.

Consideration of management alternatives

Limits on fishery catch via annual catch limits are themselves a statutorily required management approach. However, the calculation methods for MSY, OY, status determination criteria, annual catch limits, and annual catch targets are not set in stone. MSY can be estimated using catch and fishing effort data, population size and growth rate, or other proxies for reproductive potential. Similarly, incorporation of social, economic, and ecological considerations in OY and the ultimate determination of an annual catch limit or target are not uniform across fisheries. Thus, a great deal of debate goes in to discussion of alternative approaches to managing different fisheries. Very rarely is the best way forward objectively clear. Additionally, a variety of alternative management measures are considered to limit exploitation in the fishery and to reduce other issues such as bycatch, habitat damage, and overcapitalization of the fishery. Example management alternatives to address these issues include gear restrictions, temporal or spatial closures, and effort restrictions. In analyzing alternatives, national standard 8 requires that managers minimize negative effects on fishing communities to the extent practicable.[28]

- Alternative methods for calculating reference points for each fishery are considered.
- A variety of **management alternatives** for limiting effort and ecosystem impact are considered.

Public engagement

The public is engaged at several steps during the overall management process.[29] **Public and stakeholder input is sought** when determining the methods for calculating harvest limits and when discussing management options for limiting effort and ecosystem impacts.

[27] 50 C.F.R. § 600.310(g)(4).

[28] 16 U.S.C. §§ 1851(a)(8) & 1853(a)(9); 50 C.F.R. § 600.345.

[29] *See e.g.*, 16 U.S.C. §§ 1852(i) & 1854(a–b).

Monitoring and Iteration

Each FMP must include a mechanism for **periodic reassessment** of the OY specification[30] and annual catch limits must be **updated regularly** based on the best scientific information available.[31]

The relationship between MSY, OY, and the setting of harvest limits in current management practice is neither straightforward nor uniform throughout U.S. fisheries. The precise relationship between OY and the setting of annual catch limits is not clear in NMFS guidance. As a result, no uniform practice for incorporating the OY considerations (e.g., ecosystem concerns) into the annual catch limits exists. In some cases, catch limits are based on a calculation of OY, while in others the OY is the average amount of fish caught over the course of several years with catch limits calculations occurring annually based on proxies of MSY. These distinctions make a one-size-fits-all crosswalk to tipping points concepts impossible, however, several generalizations can be made. First, as a statutory rule, every fishery is managed via numerical targets and limits.[32] Second, stock assessments or the annual calculation of numerical limits should consider both species-specific thresholds and ecosystem-level concerns.[33] Third, risk and uncertainty are incorporated at various stages of the process.[34] And finally, public input, monitoring, and review are integral aspects of fisheries management, including ongoing research and annual recalculations of harvest limits based on the best available scientific information.[35] Thus, broad alignment exists between the OTP process and the current designation of status determination criteria and harvest limits under the Magnuson-Stevens Act.

Case Study – PFMC Management of Coastal Pelagic Species

The Coastal Pelagic Species (CPS) FMP defines the technical process through which an overfishing limit, OY, acceptable biological catch, annual catch limits, and yearly harvest targets are set for Pacific sardine and Pacific Mackerel.[36] This process includes input from NOAA agency scientists, a scientific peer-review panel, the Pacific Council's scientific and statistical committee (SSC) (providing additional scientific review), the CPS Management Team (to discuss management strategies), and CPS Advisory Subpanel (providing stakeholder perspectives).[37] While the estimation of MSY and the default method for calculating harvest guidelines are long-term constants set by the CPS FMP and implementing regulations, the OFL,

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[30] 16 U.S.C. § 1852(h)(5); 50 C.F.R. § 600.310(e)(3)(iii).

[31] 50 C.F.R. § 600.310(f)(4)(i).

[32] 16 U.S.C. § 1853(a)(15).

[33] 50 C.F.R. §§ 600.310(e)(3)(iv) and 600.310(f)(4).

[34] *See e.g.*, 50 C.F.R. § 600.310(f)(3).

[35] 50 C.F.R. § 600.310(f)(4)(i); 16 U.S.C. §§ 1852(i) & 1854(a–b).

[36] The FMP also defines the process for setting overfishing limits, acceptable biological catch, and annual catch limits for several "monitored" stocks: Northern anchovy, jack mackerel, and market squid. Pacific Fishery Management Council, Coastal Pelagic Species Fishery Management Plan: as Amended Through Amendment 15, at 40 (Feb. 2016) (hereinafter CPSFMP) *available at* http://www.pcouncil.org/wp-content/uploads/2016/05/CPS_FMP_as_Amended_thru_A15.pdf.

[37] CPSFMP at 43–45.

ABC, ACL, and harvest guidelines are calculated annually based on estimates of biomass and the OY considerations. For a full explanation of the CPS technical process, *see* Pacific Fishery Management Council, Coastal Pelagic Species Fishery Management Plan: as Amended Through Amendment 15, 35–40 (Feb. 2016).

1. The process begins with an estimation of MSY or MSY proxy, the statutorily defined **threshold of concern**.
2. An overfishing limit is set at an annual amount of catch that corresponds with MSY or MSY proxy harvest rates as applied to the current best estimate of biomass.
3. Acceptable biological catch is set below the overfishing limit, incorporating **scientific uncertainty** in biomass and the probability of overfishing, i.e., the Council's **chosen level of risk** aversion. The scientific uncertainty is in some cases merged with social, ecological, and economic considerations.
4. OY is less than or equal to the acceptable biological catch. Because the abundance and productivity of coastal pelagic species is known to fluctuate widely from year to year, the OY emphasis is on maintaining a constant level of biomass, rather than maintaining a constant level of catch as contemplated by the Magnuson-Stevens Act.
5. The annual catch target—an annual **regulatory limit**—is set annually and must be less than or equal to the acceptable biological catch. Considerations during this process include the status of the ecosystem, predator-prey interactions, or oceanographic conditions that may warrant additional ecosystem-based fisheries management considerations. The annual harvest limit is set with **public input** and is based on information from NMFS monitoring activities. The annual catch limit is a hard cap on fishing that, if exceeded, leads to closure of the fishery.
6. **Harvest targets**/guidelines—numerical catch objectives that do not require closure of the fishery when attained—are calculated annually using a harvest control rule. These are similar to annual catch targets. The default harvest control rule for CPS is:

   $$(\text{Biomass} - \text{Cutoff}) * \text{Fraction} * \text{Distribution}$$

   Biomass is the current estimate of biomass, *cutoff* is the lowest level of biomass at which directed harvest is allowed, *fraction* is the fraction of biomass that can be taken by the fishery, and *distribution* is the percentage of the stock in the U.S. exclusive economic zone. Both *cutoff* and *fraction*, as well as an additional optional parameter of *maximum catch*, incorporate OY considerations including environmental conditions and social, economic, and ecological considerations. For example, the designated *fraction* for sardines of 5–20% is a policy decision taken by the Council to protect sardine as forage for the ecosystem (**ecosystem threshold of concern**) and to account for variability in sardine productivity due to environmental conditions (i.e., water temperature).[38]

[38] Pacific Sardines exhibit higher productivity in warmer water. Thus, the harvest control rule provides for a greater harvest in warm water years, as determined by the average sea-surface temperature from a single monitoring station over a three-year period. CPSFMP at 40. Unfortunately, while this rule provides an example of incorporating fluctuating water temperature into stock management, additional science indicated that the control rule as a whole was insufficient to protect the sardine population. *See* Pacific Fishery Management Council, Decision Summery Document (Apr. 2016) available at http://www.pcouncil.org/wp-content/uploads/2016/04/0416decisions.pdf. The control rule was insufficient in part because the single monitoring station used was not an appropriate indicator of sardine productivity and biomass calculation updates were not updated in a timely manner. *See* Felipe Hurtado-Ferro

Additionally, a maximum level of catch is specified for sardine as a socioeconomic consideration to avoid overcapitalization of the fleet (**socioeconomic threshold of concern**) during years of high abundance.

OFL	BIOMASS * F_{MSY} * DISTRIBUTION
ABC	BIOMASS * BUFFER * F_{MSY} * DISTRIBUTION
ACL	LESS THAN OR EQUAL TO ABC
HG	(BIOMASS - CUTOFF) * FRACTION * DISTRIBUTION.
ACT	EQUAL TO HG OR ACL, WHICHEVER VALUE IS LESS

Figure 1 │ Default harvest control rules and reference point equations defined in the CPS FMP.
Pacific Fishery Management Council, Coastal Pelagic Species Fishery Management Plan 38 (2016).

The FMP also defines the administrative revision process and public input requirements that must be followed prior to the setting of annual quotas or harvest guidelines by the Pacific Council. For a full explanation of the CPS administrative process, *see* Pacific Fishery Management Council, Coastal Pelagic Species Fishery Management Plan: as Amended Through Amendment 15, 43–44 (Feb. 2016).

1. A fishery assessment report is prepared and circulated that describes the current status of the species, catch data from previous years, ecosystem considerations, and recommendations for harvest specifications for the next year. The report includes **updated estimates of biomass and the subsequent recalculations** of OFL, ABC, ACL, and explores various harvest guidelines.
2. Public meetings are held by the SSC, CPS management team, CPS advisory subpanel, and the Council to **obtain public comments** and discuss the harvest recommendations.
3. NMFS makes the final determination on annual harvest specifications.
4. NMFS and the States **monitor the fishery throughout the year** in preparation for the next year's assessment report.

This case study provides an example of how thresholds of concern, risk, and public input are considered in the context of single species harvest limits under the Magnuson-Stevens Act. For sardine, the consideration of ecosystem impacts from the excessive removal of an important forage species provides an example of how managers can qualitatively account for thresholds of concern—in this case a bottom-up trophic cascade—in decision making. The sardine control rule also accounts for the influence of temperature (an ecosystem indicator) on sardine productivity (a single-species threshold of concern).

These represent both qualitative and quantitative consideration of tipping points. The forage considerations minimize the risk of crossing ecological and economic tipping points to some

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and Andre E. Punt, Revised Analysis Related to Pacific Sardine Harvest Parameters (2014) available at http://www.pcouncil.org/resources/archives/briefing-books/march-2014-briefing-book/#cpsMar2014.The Council has since updated the rule to use a more appropriate temperature monitoring station. Pacific Fishery Management Council, Decision Summary Document (Mar. 2014) *available at* http://www.pcouncil.org/wp-content/uploads/0314decisions.pdf. Also note that the fraction range of 5-20% was revised from the original FMP range of 5-15% in 2014. Pacific Fishery Management Council, Status of the Pacific Coast Coastal Pelagic Species Fishery and Recommended Acceptable Biological Catches: Stock Assessment and Fishery Evaluation 2014, at 31 (2014) *available at* http://www.pcouncil.org/wp-content/uploads/2014_CPS_SAFE_Text_FINAL.pdf.

extent, but the CPS FMP lacks explicit quantitative linkages between predator needs and the harvestable biomass.[39] The overall reduction of harvestable biomass to 20% to protect these species' forage role is based on a qualitative understanding of ecosystem needs and precautionary management.[40] Alternatively, the range in *fraction* is based on an empirically established and quantitative relationship between water temperature and sardine productivity. The complexity in this control rule may not be possible for managing fish stocks that exhibit weaker or less consistent linkages with ecosystem effects.

A Transition to Ecosystem-Based Fisheries Management

Under the current stock- or stock complex-focused management approach mandated by the Magnuson-Stevens Act and outlined above, true consideration of ecosystem thresholds and ocean tipping points is rare. Impacts, uncertainty, and risk are addressed per stock or stock complex rather than at the ecosystem level. The stage in the process at which ecosystem concerns are considered varies depending on the management approach for each fishery, and managers have generally engaged in implicit or purely qualitative incorporation of ecosystem concerns. Many recognize this as a narrow approach to managing marine species that interact with their ecosystem in complex ways.[41]

This recognition has led to a push for ecosystem-based fisheries management and research on the use of ecosystem indicators in fisheries management. Ecosystem indicators can serve a variety of functions. Primarily, they perform a descriptive function: they represent proxy indicators for the health of entire ecosystems and can be used to indicate whether management measures are successfully achieving objectives. Ecosystem level indicators that perform a prescriptive function (i.e., are tied directly to a management response) are rare. Prescriptive indicators must monitor a meaningful aspect of the ecosystem and link a threshold in the indicator with a decision rule. Example ecosystem indicators include physical indicators (e.g., temperature), trophodynamic indicators (e.g., average trophic level of catch), biomass indicators (e.g., relative biomass or biomass ratios), size-based indicators (e.g., size structure of the community), and diversity indicators (e.g., taxonomic diversity). Ecosystem-based fisheries management should also include consideration and indicators of social, economic, and cultural health[42] such as changes in community stability, employment, income, or food security.

Although the concept of optimum yield arguably provides a workable framework for incorporating ecosystem concerns, the Magnuson-Stevens Act contains no explicit mandate to conduct this type of ecosystem-level planning. As a result, there is a paucity of tools to

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[39] However, scientists continue to make progress towards quantitative understanding of predator-prey relationships for CPS. *See* Andre E. Punt et al., Exploring the implications of the harvest control rule for Pacific sardine, accounting for predator dynamics: A MICE model, 337 Ecological Modelling 79 (2016).

[40] Amendment 8 to the Coastal Pelagic Species Fishery Management Plan, Appendix B, 91–101 (1998) *available at* http://www.pcouncil.org/wp-content/uploads/cpsa8_cover_toc_es.pdf.

[41] *See e.g.*, Ecosystems Principles Advisory Panel, Ecosystem-based Management—A Report to Congress 2, 27 (April 1999) available at http://www.nmfs.noaa.gov/sfa/EPAPrpt.pdf; E. K. Pikitch et al., Ecosystem-Based Fishery Management, 305 Sci. 346–47 (2004).

[42] 16 U.S.C. § 1851(a)(8); 50 C.F.R. § 600.345.

incorporate ecosystem indicators into ecosystem- or species-level management and harvest controls via the Council management process. Nevertheless, innovation is occurring at the Council level in certain regions. And NOAA Fisheries' recently released Ecosystem-Based Fisheries Management Policy and forthcoming Roadmap commit the agency to study ecosystem processes, explore and address trade-offs within ecosystems, and incorporate ecosystem considerations into management advice.[43]

Background – Fishery Ecosystem Plans

The identification and incorporation of ecosystem-level concerns into management is primarily occurring through the creation of Fishery Ecosystem Plans (FEPs). In 1996, Congress charged NMFS with convening an expert panel to assess how ecosystem principles were being applied in fisheries management and develop recommendations for integrating ecosystem principles into future fisheries management.[44] The Ecosystem Principles Advisory Panel produced a report in 1999 recommending that Councils develop FEPs.[45] Since 2007, four of the eight Councils have created and adopted a total of eight fishery ecosystem plans[46] and additional plans are in development. As ecosystem science continues to evolve, these FEPs may provide early models of management frameworks that can integrate ecosystem tipping points thinking into fisheries management.

Case Study – Ecosystem Indicators in the Aleutian Islands Fishery Ecosystem Plan

The Aleutian Islands Fishery Ecosystem Plan (AIFEP) includes an environmental assessment that identifies ecosystem interactions that the Council should monitor in order to avoid changes to potentially undesired ecosystem states. The assessment recognizes the existence of non-linearities and regime shifts and how they relate to fishery collapses and rebuilding difficulties. While recognizing that some ecological assessments can provide quantitative estimates of risk or threshold points, for various reasons the AIFEP assessment is qualitative and based on expert opinion. As such, the results of the assessment are primarily descriptive and intended only to

[43] National Marine Fisheries Service, Ecosystem-Based Fisheries Management Policy (2016) *available at* http://www.nmfs.noaa.gov/op/pds/documents/01/01-120.pdf; *Ecosystem-Based Fishery Management Policy and Roadmap*, NOAA Office of Science and Technology: National Marine Fisheries Service (last visited Nov. 2, 2016) https://www.st.nmfs.noaa.gov/ecosystems/ebfm/creating-an-ebfm-management-policy.

[44] Ecosystems Principles Advisory Panel, Ecosystem-based Management—A Report to Congress 2, 27 (April 1999) (hereinafter EPAP), available at http://www.nmfs.noaa.gov/sfa/EPAPrpt.pdf.

[45] EPAP at 27. The report of the Advisory Panel provides that "[t]he objectives of FEPs are to: Provide Council members with a clear description and understanding of the fundamental physical, biological, and human/institutional context of ecosystems within which fisheries are managed; [d]irect how that information should be used in the context of FMPs; and [s]et policies by which management options would be developed and implemented."

[46] The following FEPs exist: Aleutian Islands Fishery Ecosystem Plan from the North Pacific Fishery Management Council; Pacific Coast Fishery Ecosystem Plan for the U.S. Portion of the California Current Large Marine Ecosystem from the Pacific Fishery Management Council; five Western Pacific Fishery Ecosystem Plans (American Samoa, Marianas, Hawaii, Pacific Remote Islands Area, and Pelagics) from the Western Pacific Fishery Management Council; and the South Atlantic Fishery Ecosystem Plan from the South Atlantic Fishery Management Council. *Fishery Ecosystem Plans*, NOAA Office of Science and Technology (last visited Aug. 10, 2016) https://www.st.nmfs.noaa.gov/ecosystems/ebfm/fishery-ecosystem-plan.

identify ecological interactions for further attention. This portion of the AIFEP currently has no prescriptive or decision-making function.

The risk assessment identifies a wide range of important ecosystem interactions and associated indicators. A total of 22 interactions are explored across five broad categories: climate, predator-prey, fishing effects, regulation, and socioeconomic activities. These interactions are summarized in Figure 2.

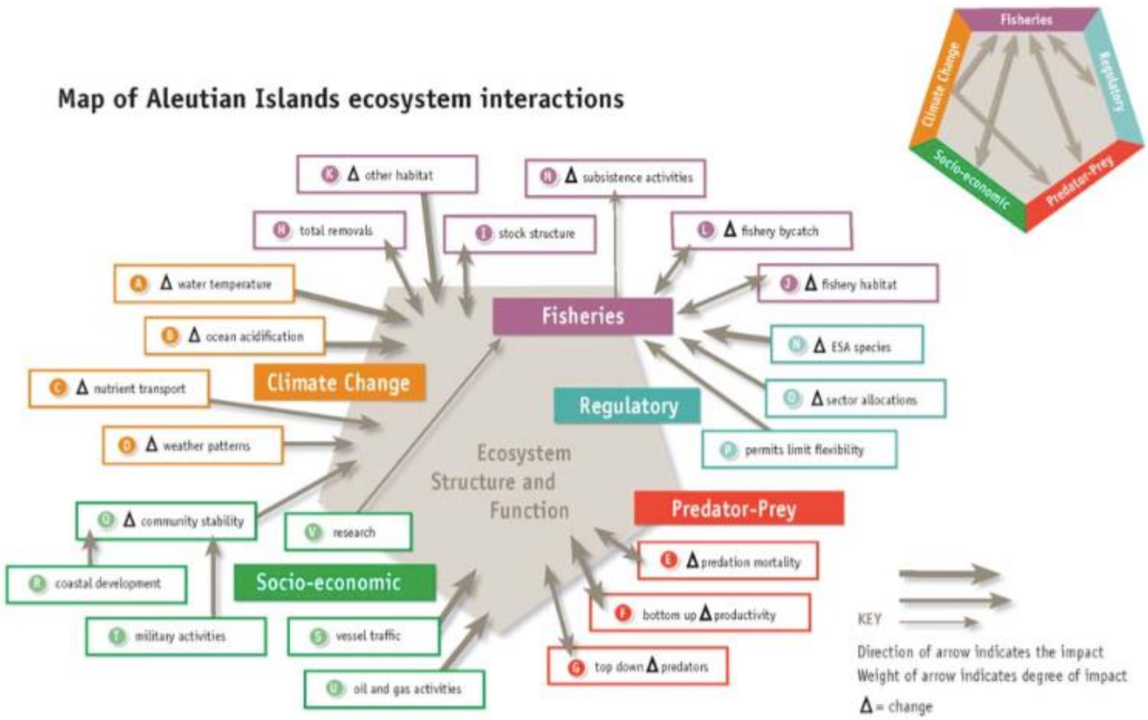

Figure 2 | Map of ecosystem interactions, and direction and intensity of impacts.
North Pacific Fishery Management Council, Aleutian Islands Fishery Ecosystem Plan 131 (2007).

For each type of interaction, the assessment provides examples of ecosystem impacts, probabilities of occurrence, economic consequences, spatial and temporal scales, implications for management, a variety of indicators that may be useful for monitoring the interactions, and data gaps. These qualitative discussions provide general information about the probability and intensity of potential ecological or economic impacts associated with changes in ecosystem interactions. The assessment also identifies useful indicators for measuring interactions—some of which are already monitored—but leaves the creation of explicit linkages to management decisions for another day.

The AIFEP risk assessment process is very similar to the approach outlined by the Ocean Tipping Points project:

1. The risk assessment began with identifying ecosystem interactions that should be monitored to avoid changes to potentially undesirable ecosystem states, or **thresholds of concern**. At the outset, the assessment explicitly references "threshold levels" and "regime shifts" and textually and visually conceptualizes the existence of non-linearities

and their relationship to fishery collapses and rebuilding difficulties.[47] The relevant ecosystem interactions are the **drivers of those thresholds**.

2. The assessment then identifies the probability of occurrence for thresholds and the nature and level of economic and ecological impacts or harm from the potential threshold. The probability of occurrence is effectively an **analysis of the risk of crossing a threshold**. And the analysis of resulting impacts and harm are intended to inform **social preferences** and **risk tolerance to the changes that could result**. Due to time constraints, the AIFEP risk assessment conducted a probabilistic analysis that declined to quantify risk.
3. The assessment also **identified leading indicators** that are expected to signal the approach of the thresholds of concern. The assessment categorizes these indicators as currently monitored, data available but not monitored, or data not currently available. Currently monitored indicators include bottom temperature, trophic level catch, predator population health, and age, length, and frequency data. Determining the relationship between ecosystem or species thresholds and these currently monitored indicators are research priorities for the region.

The stated purpose of the risk assessment is ultimately to "provide managers with a tool to either make choices between different risks or to take actions to avoid, buffer or mitigate the risk all together through appropriate management actions."[48] The assessment is intended to help decision makers **develop future management scenarios and evaluate management alternatives**. In part, the risk assessment states:

> Ideally, each indicator is associated with reference points and thresholds, the passing of which would indicate a large undesired shift, and consequently might trigger a management action. Ultimately, in a quantitative model, the change in the indicators would trigger management actions in relation to defined reference points, and an audit function model would assess the effectiveness of triggered management actions.[49]

However, the AIFEP **declines to set target and limits based on the thresholds, social preferences, and risk analysis** that would tie the indicators directly to management decisions. The assessment explicitly recognizes this as an essential next step.[50]

The ecosystem indicators outlined in the AIFEP have been further developed into an Aleutian Islands ecosystem assessment and are tracked on an annual basis as part of the Council's Ecosystem Considerations appendix to the Groundfish Stock Assessment and Fishery Evaluation Report.[51] As part of this effort, ecosystem indicators are also tracked for the Gulf of Alaska,

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[47] North Pacific Fishery Management Council, Aleutian Islands Fishery Ecosystem Plan 71–72 (2007).

[48] North Pacific Fishery Management Council, Aleutian Islands Fishery Ecosystem Plan 72 (2007).

[49] North Pacific Fishery Management Council, Aleutian Islands Fishery Ecosystem Plan 73 (2007).

[50] North Pacific Fishery Management Council, Aleutian Islands Fishery Ecosystem Plan 74 (2007) ("An essential research topic is to determine critical threshold levels for most of these indicators as well as to determine what the appropriate associated management actions should be.").

[51] North Pacific Fishery Management Council, Ecosystem Considerations 2015: Status of Alaska's Marine Ecosystems (Dec. 2015) *available at* http://www.afsc.noaa.gov/REFM/Docs/2015/ecosystem.pdf.

Bering Sea, and Arctic regions under the North Pacific Council's jurisdiction.[52] The Ecosystem Considerations document contains report cards, ecosystem assessments, and information on recent trends in identified ecosystem indicators. The goal is to provide stronger links between ecosystem research and fishery management. Despite this progress, the indicators remain uncoupled from management decision making. The methods for setting targets and limits developed by the Ocean Tipping Points project (step 4b) may assist the effort to tie the indicators directly to management decisions.

The FEP management framework provides the perfect vehicle for incorporating these ecosystem indicators into management. However, as evidenced by the AIFEP risk assessment, quantitative understanding of ecosystem thresholds proves elusive, time-consuming, and costly in the fisheries context. Additionally, tools to incorporate ecosystem level indicators into management decisions must be developed. The temperature parameter included in the sardine harvest control rule is one (albeit imperfect, *see* note 38) example of such a connection.

Conclusion

The Magnuson-Stevens Act allows for consideration of relevant thresholds through the designation of optimum yield and harvest limits. Species-level thresholds rooted in levels of biomass or exploitation are in fact an integral part of managing for sustainable fisheries. But quantifying, or even identifying, ecosystem-level thresholds presents a challenge due to the complex nature of marine ecosystems. Additionally, the Magnuson-Stevens Act contains no *explicit* mandate to conduct ecosystem-based fisheries management. This is reflected in both the absence of decision making approaches that focus on ecosystem-level overfishing and the lack of available tools for linking ecosystem thresholds and indicators to stock or fishery-level management decision making. As a result, incorporation of ecosystem threshold concerns into current management decisions is sporadic. To the extent they are incorporated, ecosystem concerns frequently take the form of percentage reductions in harvest limits for individual species or stocks based on the relevant species' functional group.

Currently, the exact approach for managing individual fisheries in the United States varies widely based on the available information and scientific understanding relevant to each fishery. Some are managed using stock-specific thresholds derived from historical catch and driven in large part by politics and reactive crisis management. Others have scientifically-calculated stock-specific thresholds based on complex understanding of the stock's life history and current abundance. The incorporation of ecosystem-level concerns is similarly diverse. For example, some fisheries incorporate ecosystem concerns directly into stock assessment models. Others incorporate ecosystem concerns by reducing allowable catch, making policy decisions based on the stock's ecosystem role or on a complex linkage between species productivity and a relevant ecosystem indicator (e.g., sardine control rule, see above).

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[52] *See* most recent assessment reports on the Alaska Marine Ecosystem Considerations website. *Alaska Marine Ecosystem Considerations*, NOAA.gov (last visited June 16, 2016) http://access.afsc.noaa.gov/reem/ecoweb/index.php.

The Magnuson-Stevens Act and NMFS guidance provide flexibility to manage these species and their important ecosystem roles more holistically—including quantitative thresholds with direct management implications—if available scientific information allows. For example, models that quantify or predict predator-prey interactions or predator response to the exploitation of prey can enable calculation of forage biomass levels necessary to avoid decline in predator biomass, allowing a more scientifically based threshold to avoid trophic thresholds of concern.[53] Many scientists, managers, and stakeholders suggest that a more formal process for considering these ecosystem-level risks would improve outcomes. Thresholds based on scientific limits can improve ecological, economic, and social outcomes by more narrowly defining the safe operating space for management, allowing greater confidence in annual harvest limits and higher catch in years of abundance. Clearly-defined quantitative thresholds and risk policies can also remove some of the politically-driven decision making that has become common at the Council level.

Tipping points science provides a useful lens for managing fisheries using both species- and ecosystem-level thresholds under the Magnuson-Stevens Act. Specifically, the process of identifying thresholds of concern, drivers, and targets or limits closely tracks the existing management methods outlined above. However, the systematic OTP process can help tighten the current practice of considering tipping points in the managed system. The OTP process can also greatly expand the incorporation of social and cultural concerns and impacts into management decisions. Additionally, the process provides an explicit framework within which to replicate the ecosystem risk assessment of the North Pacific Fishery Management Council and continue progress towards ecosystem-based fisheries management. While the essential considerations outlined by the Ocean Tipping Points project are not new to managers, the systematic process and guidance provided for identifying and managing thresholds of concern can improve the incorporation of thresholds into fishery management decisions.

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[53] Lenfest Forage Fish Task Force, Little Fish Big Impact 67–72 (2012) *available at* http://www.oceanconservationscience.org/foragefish/files/Little%20Fish,%20Big%20Impact.pdf. In the absence of quantifiable thresholds, the precautionary approach taken by the CPS FMP is favored. *Id.* at 90.