Use of annual catch limits to avoid stock depletion in the Bering Sea and Aleutian Islands management area (Northeast Pacific)

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DiCosimo, J., Methot, R. D., and Ormseth, O. A. 2010. Use of annual catch limits to avoid stock depletion in the Bering Sea and Aleutian Islands management area (Northeast Pacific). – ICES Journal of Marine Science, 67: 1861–1865.

In total, 41 fish stocks in US ocean waters continue to be fished at unsustainable levels, and 46 fish stocks are overfished. In 2006, the US Congress required the implementation of annual catch limits (ACLs) and accountability measures by 2010 to prevent overfishing, and by 2011 to recover overfished stocks. These requirements were modelled on the existing management system for Northeast Pacific groundfish, where more than 20 fish stocks and assemblages have been managed sustainably for 30 years. Science-based overfishing levels and acceptable biological catches (ABCs) have been implemented for each stock or assemblage, with buffers between the two to avoid overfishing. Total allowable catches are set at or below the acceptable biological catch. Suballocations of quotas by season, area, and gear type, along with in-season fishery closures based on extensive observer coverage and vessel monitoring, ensure that quotas are not exceeded. To comply with ACL requirements, the North Pacific Fishery Management Council has defined ABC as an ACL. We demonstrate the effectiveness of ACLs for successful management of Northeast Pacific groundfish, suggesting that their use in other US fisheries might reduce the risk of overfishing and enhance the recovery of overfished stocks.

Keywords: acceptable biological catch, accountability measures, annual catch limits, depletion, fisheries management, overfishing level, total allowable catch.

Received 6 November 2009; accepted 7 April 2010; advance access publication 29 June 2010.

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Introduction

In the United States, the 1976 Magnuson–Stevens Fishery Conservation and Management Act (MSA) established a 200 nautical miles Exclusive Economic Zone (EEZ) and a regional fishery management council system. Eight councils recommend fishery management actions to the National Marine Fisheries Service (NMFS). One of the main issues addressed in the MSA was the overfishing of marine fish stocks. Since its passage in 1976, National Standard 1 of the statute has required that conservation and management measures prevent overfishing, while achieving the optimum yield from each fishery on a continuing basis.

Overfishing continues to be a problem, not only around the globe (Worm *et al.*, 2009), but also in some US fisheries, despite more than 30 years of management by NMFS upon recommendations by the councils (Murawski *et al.*, 2007). The status of US fish stocks is evaluated using two metrics. Metric 1 uses the relationship between catch and overfishing level (OFL), which determines whether a stock is currently subject to overfishing. Metric 2 determines whether a stock is currently overfished, based on the relationship between stock size (usually in terms of spawning biomass) and the level corresponding to the maximum sustainable yield (MSY). Stocks might exhibit neither, one, or both conditions. Among the 531 stocks (or stock complexes) identified in the EEZ in 2009, 41 out of 251 (16%; data for the remaining 280 were insufficient to determine their status) assessed stocks at that time were subject to overfishing (Metric 1), whereas 46 out of 199 stocks (23%; status of remaining 332 stocks unknown) assessed were deemed overfished (Metric 2).

The US Congress established new statutory requirements under the MSA in 2006 to end and prevent overfishing by the use of annual catch limits (ACLs) and accountability measures. These new requirements must be implemented by 2010 for all stocks subject to overfishing and by 2011 for all stocks not subject to overfishing. A new provision of the MSA requires that the respective scientific and statistical committees (SSC) of the eight fishery management councils determine scientific benchmarks, while the councils continue to recommend quotas subject to these scientific benchmarks. This separation of authorities represents a major step forward in trying to eliminate overfishing and to enhance recovery of overfished stocks.

Assuming that catch is measured accurately, ACLs provide a transparent measure of the effectiveness of management practices to prevent overfishing. They cannot exceed the fishing level determined by the SSC, but also establish catch thresholds that trigger accountability measures to prevent overfishing.

Accountability measures might include: (1) seasonal, area, and gear allocations; (2) bycatch limits; (3) closed areas; (4) gear restrictions; (5) limited entry; (6) catch shares; (7) in-season fishery closures; and (8) observer and vessel monitoring requirements. Accountability measures allow close monitoring of overall catch levels, as well as seasonal and area apportionments. They might close designated areas, or fisheries, if bycatch limits for prohibited species are attained. They also allow monitoring of the take of any endangered or threatened mammals or seabirds and provide a database for evaluating likely consequences of future management actions.

None of the stocks or stock complexes in the Bering Sea and Aleutians Islands (BSAI) management area in the Northeast Pacific currently is subject to overfishing or in an overfished condition (Figure 1), largely because ACLs have been set at conservative levels for more than 30 years and fisheries are closed when quotas are met. The management process voluntarily adopted by the North Pacific Fishery Management Council (NPFMC) has been considered a model for setting national policy on ACLs and accountability measures (USCOP, 2004). The Council has consistently adopted the annual OFL and acceptable biological catch (ABC) recommendations from its SSC and set the total allowable catch (TAC) for each of its commercial groundfish stocks at or below the respective ABC. The BSAI groundfish fisheries are valued at more than $US 1000 million per year and provide more than half the volume of commercial fish landings in the United States. They provide the economic engine for more than a hundred coastal communities, thousands of vessels, and tens of thousands of workers in the fishing and processing industries throughout Alaska and the Pacific Northwest (Witherell and Dalzell, 2009). The application of ACLs and accountability measures in the Northeast Pacific is examined here to demonstrate the expected success of their application in other US fisheries where they currently are not used.

Historical development

The NPFMC first defined OFL in 1991 as a catch limit that never should be exceeded. The NPFMC adopted more conservative definitions of OFL in 1996 and again in 1999, to comply with revised national guidelines. In 1996, the NPFMC capped the rate of fishing mortality used to calculate ABC by the rate used to calculate OFL. These rates were prescribed through a set of six tiers (described below). Harvest rates used to establish ABCs were reduced at low stock size levels, thereby allowing rebuilding of depleted stocks. If the biomass of any stock falls below B_{MSY}, or a proxy for B_{MSY}, the fishing mortality is reduced relative to the stock status. In 1999, the NPFMC prescribed that OFL should never exceed the amount that would be taken if the stock were fished at F_{MSY} (or a proxy for F_{MSY}), after Congress redefined the terms "overfishing" and "overfished" to mean a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce MSY on a continuing basis. The OFL could be set lower than catch at F_{MSY} at the discretion of the SSC. Because Tiers 2–4 could be interpreted as treating MSY as a target rather than as a limit, the NPFMC revised those tiers by changing the default value for the rate of fishing mortality from $F_{30\%}$ (the rate that reduces equilibrium biomass to 30% of its unfished level under an assumption of constant recruitment) to the more conservative estimate of $F_{35\%}$.

The buffer between OFL and ABC accounts for uncertainty in single-species stock assessments, ecosystem considerations, and operational constraints in managing the fishery. The SSC sets these management benchmarks based on scientific standards. Finally, the Council determines the TAC based on social and economic considerations. In application, the NPFMC sets TAC $\leq$ ABC $<$ OFL. Under the new requirements, ACL = ABC.

In 2005, Congress implemented an optimal yield cap of 2 million tonnes on the sum of the BSAI groundfish TACs, which had also been part of the BSAI Groundfish Fishery Management Plan (FMP) since 1982 based on social, economic, and ecological considerations. The TAC for any stock could be reduced below its corresponding ABC to keep the sum of the TACs below the cap, to limit incidental catches of other fish, to account for groundfish removals in coastal waters (within three nautical miles) managed by the State of Alaska, or for other reasons that may be determined by the NPFMC. The decision of which TACs to reduce is negotiated by fishing industry representatives or, if an industry consensus cannot be reached, by the Council. Actual groundfish harvests have averaged approximately 90% of the cumulative TAC and 65% of the cumulative ABC (Figure 2), because of the complex array of accountability measures governing these fisheries.

The biological reference points have evolved over the past 20 years. In 1996, the Council redefined OFL and ABC, partly to

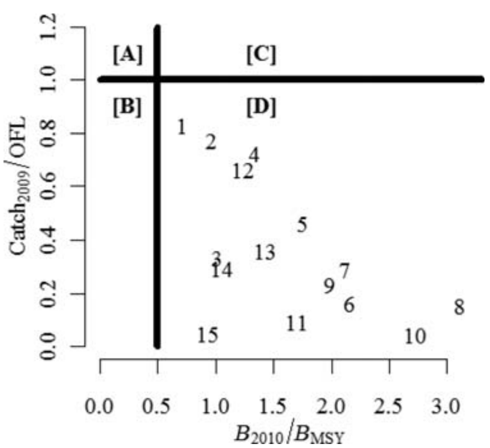

Figure 1. Summary status of Northeast Pacific groundfish species based on age-structured assessments for 2009 catch levels relative to the OFL (defined as the catch at F_{MSY}) and the projected 2010 spawning biomass relative to B_{MSY}: [A], subject to overfishing and overfished; [B], not subject to overfishing, but overfished; [C], subject to overfishing, but not overfished; [D], not subject to overfishing and not overfished (1 = walleye pollock; 2 = Pacific cod; 3 = sablefish; 4 = Atka mackerel; 5 = yellowfin sole; 6 = northern rock sole; 7 = Greenland turbot; 8 = arrowtooth flounder; 9 = flathead sole; 10 = Alaska plaice; 11 = skates; 12 = Pacific ocean perch; 13 = northern rockfish; 14 = blackspotted and rougheye rockfish; 15 = Aleutian Islands walleye pollock). Figure courtesy J. Ianelli.

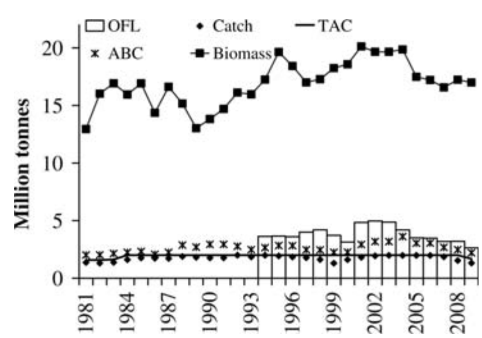

Figure 2. Cumulative estimates of biomass, overfishing level (OFL), acceptable biological catch (ABC), total allowable catch (TAC), and actual catch (all in million tonnes) across all groundfish species in the Northeast Pacific, 1981–2009.

facilitate more conservative, risk-averse management measures when stock size and mortality rates are not fully known (with the consequence that annual TACs were reduced for many stocks or stock complexes; Figure 2). Their determination is prescribed through a set of six tiers based on the availability of various types of information (Table 1). "Data-rich" and "data-poor" are relative terms not actually used in the FMP, because the variability in the availability and quality of the data is substantial. Here, data-rich stocks are considered those for which data are sufficient to apply age-structured modelling (Methot, 2009) and have some estimate of unfished biomass (i.e. Tiers 1–4; Tier-2 and Tier-4 stocks are not present in the BSAI management area). Data-poor stocks are those where the unfished biomass cannot be estimated and catch limits are set using survey biomass estimates or historical catch data (i.e. Tiers 5–6). For many groundfish stocks, $F_{40\%}$ is used as a reference point in the ABC control rule. For Tier 3 stocks, where $B > B_{40\%}$, $F_{40\%}$ is the upper limit on F_{ABC} and $F_{35\%}$ is the F_{OFL}. For stocks for which sufficient data exist to assess current biomass (B) relative to B_{MSY} or $B_{40\%}$ (the long-term average biomass that would be expected under average recruitment and $F = F_{40\%}$), the control rules reduce the allowable F when B falls below B_{MSY} (Tiers 1 and 2) or $B_{40\%}$ (Tier 3). This serves to accelerate the rate of rebuilding should a stock fall to a low level of abundance.

A peer review of the NPFMC harvest strategy for single stocks concluded that the strategy was conservative and that the associated accountability measures were successful in keeping commercial harvests within the TACs (Goodman *et al.*, 2002). This precautionary, single-species approach is gradually developing into a more comprehensive ecosystem-based approach (Aydin *et al.*, 2007).

Table 1. Description of the groundfish tier system used by NPFMC since 1999 for defining fishing–mortality rate related to overfishing level (F_{OFL}) and to acceptable biological catch (F_{ABC}) based on the type of information available (Info).

Tier 1		Info: reliable point estimates of B and B_{MSY} and reliable pdf of F_{MSY}
	(1a)	Stock status: $B/B_{MSY} > 1$
		$F_{OFL} = m_A$: $F_{ABC} \times m_H$
	(1b)	Stock status: $a < B/B_{MSY} \leq 1$
		$F_{OFL} = m_A \times (B/B_{MSY} - a)/(1 - a)$; $F_{ABC} \leq m_H \leq (B/B_{MSY} - a)/(1 - a)$
	(1c)	Stock status: $B/B_{MSY} \times a$
		$F_{OFL} = F_{ABC} = 0$
Tier 2		Info: reliable point estimates of B, B_{MSY}, F_{MSY}, $F_{35\%}$, and $F_{40\%}$
	(2a)	Stock status: $B/B_{MSY} > 1$
		$F_{OFL} = F_{MSY}$; $F_{ABC} \leq F_{MSY} \times (F_{40\%}/F_{35\%})$
	(2b)	Stock status: $a < B/B_{MSY} \times 1$
		$F_{OFL} = F_{MSY} \times (B/B_{MSY} - a)/(1 - a)$; $F_{ABC} \leq F_{MSY} \times (F_{40\%}/F_{35\%}) \times (B/B_{MSY} - a)/(1 - a)$
	(2c)	Stock status: $B/B_{MSY} \leq a$
		$F_{OFL} = F_{ABC} = 0$
Tier 3		Info: reliable point estimates of B, $B_{40\%}$, $F_{35\%}$, and $F_{40\%}$
	(3a)	Stock status: $B/B_{40\%} > 1$
		$F_{OFL} = F_{35\%}$; $F_{ABC} \leq F_{40\%}$
	(3b)	Stock status: $a < B/B_{40\%} \leq 1$
		$F_{OFL} = F_{35\%} \times (B/B_{40\%} - a)/(1 - a)$; $F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - a)/(1 - a)$
	(3c)	Stock status: $B/B_{40\%} \leq a$
		$F_{OFL} = F_{ABC} = 0$
Tier 4		Info: reliable point estimates of B, $F_{35\%}$, and $F_{40\%}$
		$F_{OFL} = F_{35\%}$; $F_{ABC} \leq F_{40\%}$
Tier 5		Info: reliable point estimates of B and natural mortality rate M
		$F_{OFL} = M$; $F_{ABC} \leq 0.75 \times M$
Tier 6		Info: reliable catch history from 1978 to 1995
		OFL = average catch (1978–1995), unless otherwise established by SSC; ABC $\leq 0.75 \times$ OFL

a, 0.05 for Tiers 1–3, by applying the 10% rule (Rosenberg *et al.*, 1994) to half of the B_{MSY} reference point; *B*, current biomass; subscripts MSY, 35%, and 40%, biomass related to the maximum sustainable yield, or to 35% or 40% of the unexploited biomass (or to the *F* related to those); pdf, probability density function; m_A and m_H, arithmetic and harmonic mean of the pdf.

Table 2. Species (groups) included in the two BSAI Groundfish FMP Categories proposed for 2011.

Target species: commercially important species (groups) for which ACLs are established.
Management goal: to optimize yields.
Include (by tier group):

Tier 1a	Yellowfin sole; northern rock sole
Tier 1b	EBS walleye pollock
Tier 3a	Greenland turbot; arrowtooth flounder; flathead sole; Alaska plaice; Pacific ocean perch; northern rockfish; Alaska skate
Tier 3b	AI walleye pollock; Pacific cod; Sablefish; AI blackspotted and rougheye rockfish
Tier 5	"Other" flatfish; shortraker rockfish; EBS blackspotted and rougheye rockfish; "other" rockfish; sculpins; "other" skates
Tier 6	sharks; squid; octopus

Ecosystem component: species (groups) that are not (1) targeted for harvest; (2) likely to become overfished; (3) likely to become subject to overfishing; or (4) generally retained for sale or personal use.

Prohibited species: species for which resources were fully utilized before the FMP was implemented must be returned to the sea with a minimum of injury when caught in groundfish fisheries, because they are targeted directly in other domestic fisheries. Discards are counted as removals in directed fisheries.
Management goal: protection from negative effects of fishing.
Include: Pacific halibut; Pacific herring; Pacific salmon; steelhead; king crab; Tanner crab

Forage fish: 60 species that play a central role in the foodweb, and are consumed by a wide variety of fish, marine mammals, and seabirds. Directed fishing is prohibited and retention and processing of bycatch are limited.
Management goal: protection from negative effects of fishing.
Include: osmerids; myctophids; bathylagids; ammodytids; trichodontids; stichaeids; pholids; gonostomatids; euphausiids

EBS, Eastern Bering Sea; AI, Aleutian Islands.

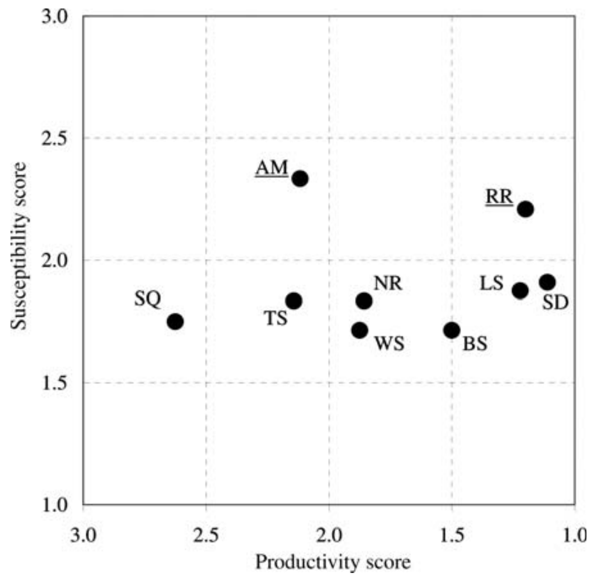

Figure 3. Selected results from a vulnerability analysis for groundfish in the Bering Sea/Aleutian Islands region. Axes represent the mean score from multiple Productivity and Susceptibility attributes. The *x*-axis is reversed, so that the origin of the plot indicates the point of lowest vulnerability (i.e. lowest Susceptibility, highest Productivity). AM, Atka mackerel; BS, bigmouth sculpin; LS, longnose skate; NR, northern rock sole; RR, rougheye rockfish; SD, spiny dogfish; SQ, squids; TS, threaded sculpin; WS, warty sculpin. Target stocks are underlined.

Stock categories

National guidelines for implementing ACLs require the classification of fish stocks. The BSAI Groundfish FMP will define two management categories beginning in 2011, namely target species and ecosystem components (Table 2). Stocks of target species—as well as some non-target stocks that are caught incidentally—are considered to be "in the fishery" and for such stocks, ACLs and accountability measures are required. The plan is to eliminate the existing "other species" category, which includes species with diverse life histories (e.g. sharks and squids) that are not currently commercially important or targeted by the fisheries. For this category, aggregate biological reference points have been set, but the NPFMC has been concerned that some of these groups could be disproportionately exploited under these aggregate limits (Reuter *et al.*, 2010). Species such as long-lived sharks, with low reproductive potential, are particularly vulnerable to depletion, because it takes them longer to rebound from fishing removals. However, a lack of life-history information and data on abundance and catch composition hampers the assessment of their stock status. Directed fishing on these groups would be prohibited, at least until knowledge of the life histories has improved.

The proposed "ecosystem component" category comprises less-impacted stocks for which ACLs will not be required, but they will be monitored and management will be aimed at limiting their incidental catches. The two components being considered are prohibited species and forage fish (which currently are also defined in the FMP).

Assessing vulnerability

To assist in making the appropriate classifications and in assembling stock complexes, a semi-quantitative methodology has been developed for assessing the vulnerability of fish stocks, particularly those considered data-poor (Patrick *et al.*, 2009). This productivity–susceptibility analysis was originally developed to classify differences in sustainability of bycatch species in the Australian prawn fishery (Stobutzki *et al.*, 2001). Productivity is determined by the natural capacity for growth and the resilience to exploitation, whereas susceptibility indicates the likely severity of fishery impacts for the population. The two parameters are evaluated by scoring a number of related attributes on a scale from 1 to 3 (low, medium, and high). Productivity is characterized by life-history traits, such as natural mortality rate and age at maturity; susceptibility attributes include spatial overlap between the stock and the fishery and stock status. The mean scores for productivity and susceptibility (the former on a reversed scale) can be plotted in a graph (Figure 3), so that the origin reflects a high productivity and a low susceptibility. The Euclidean distance from the origin can be used as a measure of the overall vulnerability of the stock.

Preliminary results suggest that, except the two target species analysed (Atka mackerel and rougheye rockfish), susceptibility scores were similar for most stocks (Figure 3). This might partly be because these stocks are part of the same groundfish complex; they are therefore subject to similar fishing impacts. Squids received a high productivity and relatively low susceptibility score and hence had a relatively low vulnerability. At the opposite extreme, rougheye rockfish (a target stock) had low productivity and higher susceptibility.

Productivity–susceptibility assessments are useful, but their use for informing management decisions could be problematic. For example, the criteria to be used in designating a vulnerability threshold for management action are unclear. Moreover, the relative importance of the productivity and susceptibility scores in determining the overall vulnerability varies among stocks and regions and it is not *a priori* obvious that they should be given equal weights. The inclusion of data-rich target stocks in the assessment might provide a sensible guideline, because non-target stocks with similar vulnerability scores to target stocks might have to be managed identically.

Dealing with uncertainty

National guidelines for implementing ACLs require taking into account the probability that a catch equal to the ABC would actually result in overfishing. This probability may not exceed 50%. By definition, if the “true” OFL is viewed as a random variable and as long as the median of the distribution is used as the specified OFL, then any ABC less than the specified OFL satisfies this requirement.

The guidelines also require the control rule for setting the ABC to articulate how the uncertainty in the OFL estimate, as well as any other scientific uncertainty affecting the assessment, is taken into account. Because the buffer between ABC and OFL varies directly with the amount of uncertainty associated with F_{MSY}, this requirement is satisfied in Tier 1. The tier system is based more on the availability of various types of data than on the accuracy of those data *per se*. Although the SSC has expressed the view that the current tier system complies with the guidelines for setting ACLs, NMFS scientists are currently exploring two approaches to account more explicitly for uncertainty in the buffer: a probability-only approach, which would set a fixed probability of exceeding the true, but unknown (because of scientific uncertainty) OFL, given ACL equals ABC; and a decision-theoretic approach, which results in a buffer that is statistically optimal from the perspective of meeting management objectives, but which is more difficult to implement than the probability-only approach. However, perhaps the greatest challenge in implementing a consistent, quantitative procedure is to formulate a method that could be used for both data-rich and data-poor stocks.

Conclusions

The NPFMC’s longstanding reliance on its SSC for setting ACLs, along with extensive use of accountability measures to enforce them, has contributed to sustainable groundfish populations in the Northeast Pacific and has become a model for regional fisheries management in the United States. All eight regional fishery management councils are amending their management plans to include ACLs and accountability measures by the statutory deadline. Although there has been resistance by some councils to move from input controls to output controls as the primary means of limiting commercial harvests, the probability of success under ACLs is expected to be higher than under the *status quo*. Research will continue regarding the assessment of vulnerable species and the methods of relating the buffer between OFL and ABC to the amount of scientific uncertainty in the Northeast Pacific.

Acknowledgements

We thank Grant Thompson, Niels Daan, Tiit Raid, and Dorleta Garcia for their editorial suggestions, which greatly improved the manuscript, and Jim Ianelli for preparing Figure 1.

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doi:10.1093/icesjms/fsq060