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Managing non-target, data-poor species using catch limits: lessons from the Alaskan groundfish fishery

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Abstract The 2006 reauthorisation of the Magnuson-Stevens Fishery Conservation and Management Act requires annual catch limits for all target and non-target species within federally managed fisheries in the United States. In Alaska, both target and non-target species in the Alaska groundfish fisheries have been managed using catch limits since the early 1990s. Non-target species that are caught incidentally in a fishery require monitoring to ensure that the population is not negatively impacted by commercial fishing. Resource assessment scientists have been challenged with obtaining sufficient data to recommend an acceptable catch level for management of these species. This paper reviews three case studies where a catch limit is determined for non-target species when certain data are limited: (1) varying levels of biomass and catch data for all species within a species group or complex; (2) adequate catch data but no biomass data; (3) emerging target fishery of data-poor species, plus an example of how a complex of ecosystem component species is managed.

KEYWORDS: catch limit, data-poor, groundfish fishery, Magnuson Stevens Reauthorized Act, stock assessment.

Introduction

As is the case in many parts of the world, fishery managers in Alaska face the difficult decision of how to assess and manage species that are caught incidentally by commercial fisheries thus raising potential conservation concerns. These species, also called non-target species, are typically of limited economic value but may be candidates for future directed commercial fisheries and may be important to the ecosystem. In addition, data regarding catch, abundance and life history traits of these species can be sparse. The current interest in ecosystem-based fishery management, as well as requirements of the recently reauthorised Magnuson-Stevens Fishery Conservation and Management Act (MSRA), has resulted in a pressing need to determine the most appropriate approach to the management of non-target species.

The MSRA requires that annual catch limits be set for all species within a fishery (both target and non-target species). Setting annual catch limits for all species within a fishery poses challenges if there are species that may be data poor. Data-poor species may be defined as those that have inadequate abundance data, lack of species identification in the data, lack of catch data or lack of life history data. In Alaska, the primary data sources used to estimate the status of groundfish stocks (both target and non-target) are

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derived from broad-scale research surveys and fishery observer data. The inherent sampling design of the broad-scale research surveys provides adequate sampling for some species, but not for all species. In addition, some species exhibit patchy distributions, reside in untrawlable habitat or occur in low abundance.

The management process of federally managed species in Alaska has traditionally been extensive and complex. The North Pacific Fishery Management Council (NPFMC) established annual catch limits for target and non-target species in the early 1990s. In support of this activity, scientists from the National Marine Fisheries Service's (NMFS) Alaska Fisheries Science Center (AFSC) collect life history information and abundance estimates from regular independent research surveys to create stock assessments. These stock assessments are presented to the NPFMC for review and are used to make management recommendations to NMFS. This process has effectively managed targeted species of the groundfish fisheries in both the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA) management areas (Fig. 1).

Successful management of the Alaskan federal groundfish fisheries has been dependent upon sound scientific advice (Witherell 2004) and on the GOA and BSAI fishery management plans (FMPs). Each FMP requires setting an annual overfishing level (OFL) for each managed stock or assemblage. Overfishing is defined as any amount of fishing in excess of the maximum fishing mortality threshold. In 1997, the FMPs included a tier system as a management tool to serve as a guideline on how to calculate OFLs and acceptable biological catch (ABC) levels for a given groundfish stock or assemblage (Table 1). The tier structure was created to allow flexibility of assessment techniques, for each species or species complex within

Table 1. Description of data needs for stock assessment criteria

Data rich
Tier1: Reliable point estimates of B and B_{msy} and reliable estimates of F_{msy}
Tier2: Reliable point estimates of B, B_{msy}, F_{msy}, $F_{30\%}$ and $F_{40\%}$
Tier3: Reliable point estimates of B, B_{msy}, $F_{30\%}$ and $F_{40\%}$
Tier4: Reliable point estimates of B, $F_{30\%}$ and $F_{40\%}$
Data poor
Tier5: Reliable point estimates of B and natural mortality rate M
Tier6: Reliable catch history from 1978–1995

F denotes fishing mortality rate, B stock biomass (or spawning stock biomass, as appropriate and the F and B levels corresponding to MSY are denoted FMSY and BMSY.

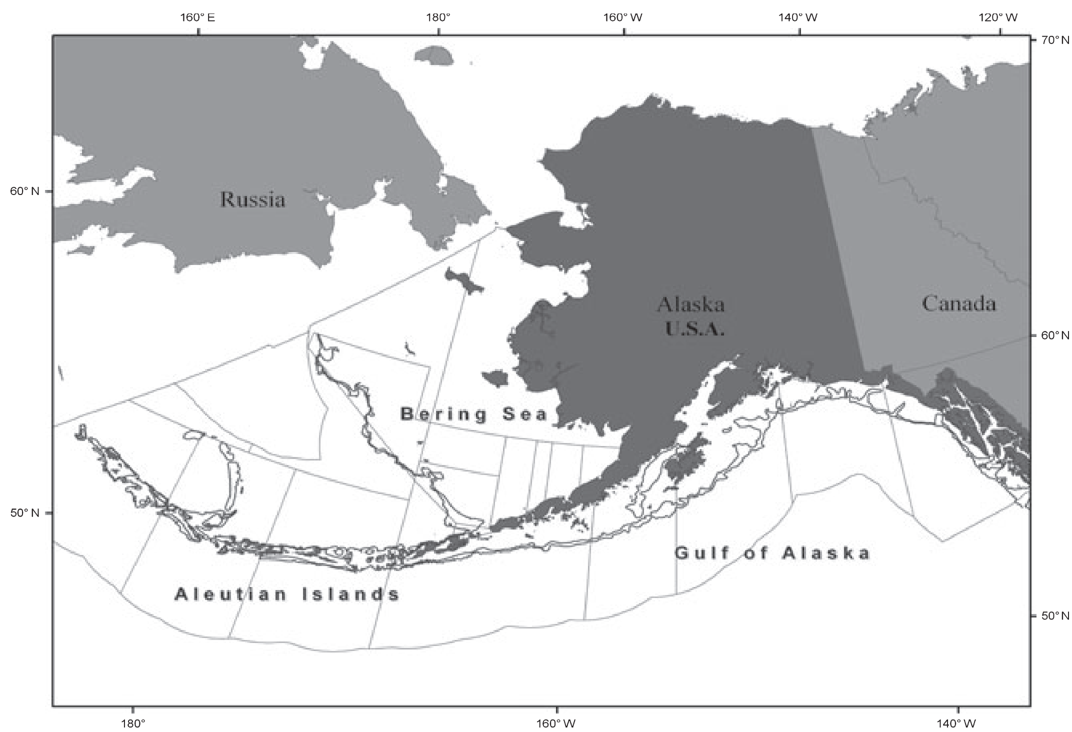

Figure 1. Map of management areas in the Bering Sea, Aleutian Islands and Gulf of Alaska.

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an FMP, where available data ranged from rich (tier 1) to poor (tier 6). Most non-target stocks are managed under tiers 5 or 6, which require adequate biomass estimates and an estimate for natural mortality (tier 5), or reliable fishery catch history (tier 6) (Table 1). At each tier, different derivations for ABC and OFL are provided. For example, at tier 6, OFL is calculated by taking the average catch over a pre-determined time period; at tier 5, OFL is calculated by multiplying a biomass (usually an average over many years) by an estimate of natural mortality; and for both tier 5 and 6, ABC is calculated as 75% of OFL. The ABC and OFL for each species or species complex within each FMP are then presented to the NPFMC for review. The NPFMC then recommends a catch limit or total allowable catch (TAC), which is usually at or lower than the ABC, to NMFS. As data availability and quality increases, the subsequent tiers use population dynamics models (which may also take into account species life history, environmental conditions and other ecological factors) to estimate ABC and OFL.

Although the tier system is a good tool to use to obtain catch limits at varying levels of data quality, other management tools may be necessary to provide appropriate protection for non-target species impacted by the Alaskan groundfish fisheries. Many non-target species in both the BSAI and GOA FMPs are managed within large generic complexes. Species within these complexes have little or often no ecological relationship. One of the largest complexes in both FMPs is called the Other Species Complex, which consists of skate, shark, squid, octopus and sculpin species groups. In these complexes, one ABC and one OFL is determined for the complex even when some species within the group may not have adequate data to assess any impact from the target fishery. In 1999, draft FMP amendments were initiated to remove the shark and skate groups from the Other Species Complex in both management areas to protect these vulnerable, long-lived species better (North Pacific Fishery Management Council (NPFMC) 1999) and to mirror action taken by the State of Alaska for state fisheries.

In this paper, four case studies are presented to illustrate how the catch limit evaluation process for data-poor, non-target species in the Alaskan groundfish fisheries depends on the type and quality of available data (Table 2). A case study of the management strategy used for an ecosystem component species complex is also presented. These case studies will describe how a catch limit is obtained when: (1) there are multiple biomass estimates and natural mortality estimates for a diverse group of species (e.g. the BSAI Sculpin Complex); (2) there are adequate catch data but poor biomass data and lack of species identification (e.g. the BSAI and GOA Octopus Complex); and (3) a target fishery quickly develops for a highly vulnerable but data-poor group of species (e.g. the GOA Skate Complex). The fourth case study uses the GOA Forage Fish Complex to demonstrate how the NPFMC managed a group of species that can be defined as ecosystem component species as described in the MSRA proposed National Standard 1 (NS1) guidelines (73 FR 32526).

BSAI sculpin complex

Background

The BSAI Sculpin Complex is managed by a catch limit based on the combined individual biomass estimates of the species within the complex. Sculpins are abundant, with an estimated total biomass in 2007 of approximately 216 000 t along the eastern Bering Sea continental shelf and 21 000 t along the Aleutian

Table 2. Non-target species in Alaskan waters

Data	Sculpin complex	Octopus complex	Skate complex	Forage fish
Fishery catch	Reliable (aggregate, mainly larger species)	Somewhat reliable	Reliable for two species, somewhat reliable for remaining 9 species Unreliable for halibut fishery	Somewhat reliable (catch of key species calculated)
Biomass	Reliable (certain species)	Unreliable	Reliable	Unreliable
Species ID	Reliable (2008 fishery data) Unreliable (pre-2008 fishery) Reliable (survey data)	Unknown (fishery) Unreliable (survey)	Somewhat reliable (from 1999-present)	Reliable
Life history	Reliable for only 5 species in AK	Proxy (none in AK)	Some age and reproductive information for select AK species	Very little age and growth information
Probable impact from fishery	Low	Low	High	Low

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Table 3. Sculpin species composition on the eastern Bering Sea shelf from the 2007 research trawl survey data

Species	Biomass (t)
Hemilepidotus jordani (Bean)	23 765
Myoxocephalus verrucosus (Bean)	13 370
Myoxocephalus polyacanthocephalus (Pallas)	63 132
Myoxocephalus jaok (Cuvier)	77 836
Hemitripterus bolini (Myers)	27 859
Gymnocanthus pistilliger (Pallas)	4126
Hemilepidotus papilio (Bean)	1653
Dasycottus setiger (Bean)	1949
Others (n = 11)	2160

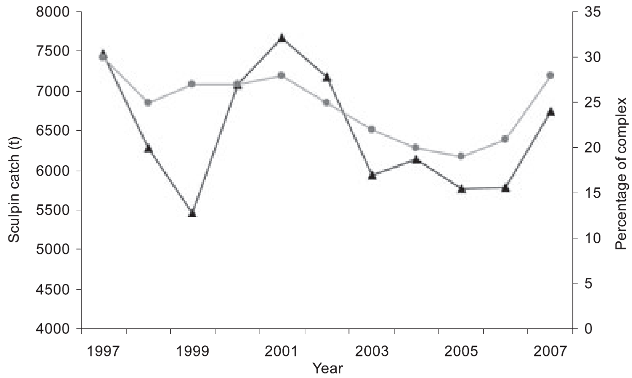

Figure 2. Sculpin fishery catch from 1997–2007 (triangle) as a percentage of the total Other Species complex fishery catch (circles).

Islands in 2006 (Reuter & TenBrink 2007). There is evidence of variability in the composition of the sculpin complex in the BSAI management area. The continental shelf is dominated by five large sculpin species [great sculpin *Myoxocephalus polyacanthocephalus* (Pallas), plain sculpin *Myoxocephalus jaok* (Cuvier), warty sculpin *Myoxocephalus verrucosus* (Bean), bigmouth sculpin *Hemitripterus bolini* (Myers) and yellow Irish lord *Hemilepidotus jordani* (Bean)], but it is also inhabited by numerous smaller species routinely caught during annual surveys (Table 3). Although not a significant portion of the total BSAI biomass estimate, the composition of sculpins on the continental slope is dominated by smaller sculpin species [darkfin sculpin *Malacocottus zonurus* (Bean), blob sculpin *Psychrolutes phrictus* (Stein & Bond) and spinyhead sculpin *Dasycottus setiger* (Bean)]. Area-specific life history information is known for the five more abundant species of sculpin. However, proxy data from similar species are used when assessing the populations of the remaining sculpin species in the BSAI.

Recent trawl survey biomass estimates for larger, common sculpin species have been reliable (CV < 0.30), but biomass estimates for the less abundant, smaller species of sculpin less so (CV range from 0.31 to 1.00) because of varying rates of selectivity. Smaller sculpin species that may be less vulnerable to capture by bottom trawl survey gear may explain this phenomenon. Depth range and distribution have been recorded since 1982 for some sculpins, while length frequency information has been collected since 2000 for the larger sculpin species. Individual length or weight data, however, are not routinely collected for the smaller species during surveys with the exception of AFSC special projects. Missing time series for exploring long-term population trends for several species has hindered the development of stock assessments for sculpins. For example, *H. jordani H. bolini* have biomass data dating back to the early 1980s in both the eastern Bering Sea and Aleutian Islands, but the most abundant sculpins along the eastern Bering Sea shelf, *M. jaok* and *M. polyacanthocephalus*, only have consistent, reliable species-specific data since 2000.

Fishery catch along the eastern Bering Sea continental shelf has contributed between 85 and 90% of the sculpin catch in the BSAI management region since 1997 (Reuter & TenBrink 2006). The total catch of the Sculpin Complex compared with the total catch of the Other Species Complex is usually about 25% (Fig. 2). In 2002, the AFSC initiated a species identification project that was prompted by the need to gather basic population data for non-commercial species. Beginning in January 2004, sculpin catch was identified to genus for the larger sculpin species of the genera *Hemilepidotus, Myoxocephalus* and *Hemitripterus*. Previously, their catch was reported as sculpin unidentified. Collectively, sculpins have exhibited a low catch-to-biomass ratio (i.e. <0.05). It is likely low because individual species catches have not been reported. Fishery catch estimates for individual sculpin species within the three main genera became a regular part of the collection programme in 2008. Previously, *H. bolini* was the only Alaskan sculpin species for which catch estimates existed (Stevenson 2004).

Current status

The top five BSAI sculpin species, in terms of biomass, in the BSAI FMP region have good biomass estimates that allow them to be assessed as a tier 5 species complex using the traditional yield-oriented management tier system. Recent identification to the species level of the top five sculpin species by fisheries observers will increase monitoring of fishing impacts. In addition, age and growth, maturity and diet

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information have been collected for several species (*M. polyacanthocephalus*, *M. jaok*, *M. verrucosus*, *H. bolini*, and *H. jordani*) as part of a comprehensive study investigating large sculpins in the BSAI. Consequently, assessment authors have suggested a method to calculate the ABC and OFL of the BSAI sculpin complex using individual biomass estimates and newly estimated natural mortalities for those sculpin species where estimates are available (Reuter & TenBrink 2007). Monitoring of these species using this method provides more conservative catch limits and allows for monitoring of individual species within the complex.

BSAI and GOA octopus complex

Background

Octopuses in Alaska are mainly harvested as incidental catch by the pot (trap) fisheries for Pacific cod, *Gadus macrocephalus* Tilesius. Octopuses are also caught incidentally in longline and bottom trawl fisheries. Although retention and sale of octopus in Bering Sea fisheries has increased from 10–20% in 1997–2002 to over 50% in 2003–2006, interest in a directed fishery for octopus in Alaska remains limited. With increasing global markets for octopus as food, ex-vessel market prices for Alaskan octopus have risen to as much as \$0.41 kg^{-1}. Since 2003, octopus have been identified and their catch recorded as a distinct category allowing estimates of total catch for the all fisheries, gear types and geographical location. This information provides time trends of commercial catch-per unit effort (CPUE) and estimated incidental catch from 1990–2008. For example, Figure 3 shows the catch trend of octopus for three different management areas within the GOA. Catch data of octopus do not show any strong indication of either increasing or decreasing abundance, but instead suggest an episodic pattern of occasional outbreaks of high abundance. This pattern is consistent with the known short life span (1–2 year or 3–5 year for most species) and pelagic larval dispersal of the dominant species, *Enteroctopus dofleini* (Wülker) (Hartwick 1983). Unfortunately, biological and life-history information on octopus in the North Pacific is limited and information for species other than *E. dofleini* is almost non-existent.

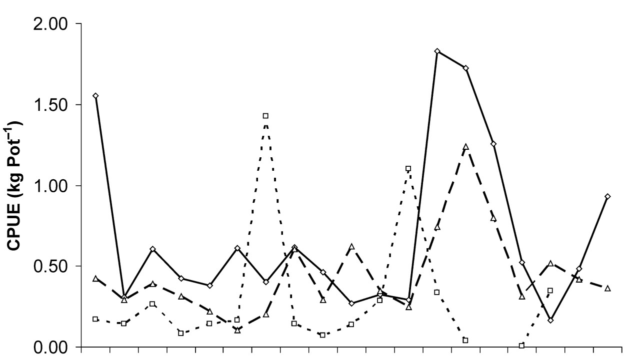

Figure 3. Example of time series of average octopus CPUE for observed hauls in selected statistical reporting areas of the GOA: annual averages for pot gear only. Statistical area 610 (diamond), 620 (square), 630 (triangle).

Preliminary assessment reports for the Octopus Complex (Conners & Jorgensen 2006, 2007) highlighted three major problems with fitting this group into the existing stock assessment process for the North Pacific. The first is that the North Pacific is inhabited by as many as nine species of octopuses. In addition to *E. dofleini*, two species of *Benthoctopus* are commonly encountered and at least two smaller species of *Octopus* currently are being described (E. Jorgensen, personal communication). This difficulty in identification to species even for trained biologists makes management at the species or even family level impractical. Species identification is suspect on older research surveys, so that there are few data on spatial or habitat-based distributions of the various species. Very large individuals are most likely to be *E. dofleini*, but smaller octopus may be one of a number of species and are easily misidentified.

The second major hurdle is that existing systems for collection of fishery-independent data are inadequate to assess octopus population trends. Management of Alaskan groundfish is based on an annual (Bering Sea) or semi-annual (Gulf of Alaska, Aleutian Islands) bottom trawl survey. Trawl gear is poorly suited to catch a representative fraction of Pacific octopus and is very poor at sampling the size fraction of octopus that is most vulnerable to fishery harvest. Over a 16-year span of Bering Sea trawl surveys, the average weight of octopus caught was <2 kg and over 50% of the individuals caught weighed <0.5 kg (Fig. 4a). By contrast, the pot gear that produces most of the incidental catch of octopus has an average weight of 12 kg, with few octopuses <2 kg being retained by the gear (Fig. 4b). The trawl survey is also conducted exclusively in waters more than 20 m deep. Octopuses are known to inhabit shallower and coastal waters in Alaska (Scheel 2002); the distribution of octopus biomass between shallow and deep waters is unknown, and may well change on a seasonal basis. Waters within 3 miles of the coastline are managed separately by the state of Alaska, which regulates octopus under its shellfish programme. In short, the federal trawl

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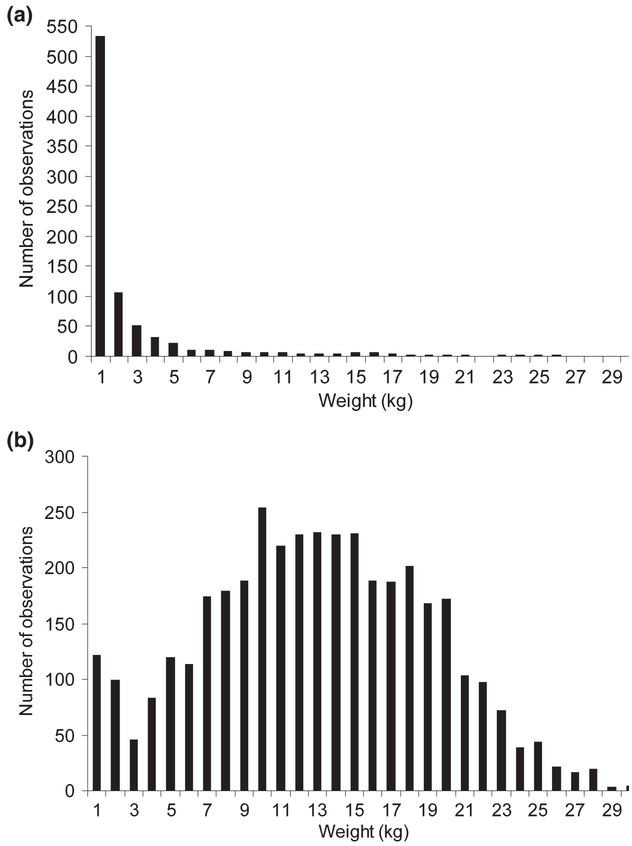

Figure 4. (a) Size frequency of individual octopus (all species) from the AFSC bottom trawl surveys in the Gulf of Alaska 1990–2005. (b) Size distribution of individual octopus in observed hauls of commercial pot gear in the Bering Sea 1987–2005.

survey provides a time series of overall estimates of octopus biomass, but the size and population fractions monitored by this survey may poorly represent the total biomass of octopus and the portion of that biomass available to the fishery.

Finally, the growth and life history patterns of octopus, like squid, are totally unsuitable for the type of age-structured assessment model used for groundfish management (Caddy 1983). Smaller species of octopuses may have a total life span of 1–2 year (Perry *et al.* 1999). *Enteroctopus dofleini* lives 4–5 year in other parts of the North Pacific (Hartwick 1983), but its life span, seasonal spawning schedule and size at maturity are unknown for Alaskan waters. Ageing structures have not been established and age-specific growth rates, maturity and catch frequencies are not available. All octopuses are terminal spawners, with mature males dying shortly after mating and females dying after incubation and hatching of eggs. Using harvest models based on proportions of natural mortality is inappropriate in this context. Other types of assessment models (surplus production models; those preserving a minimum spawning biomass) may be usable for these species (Hatanaka 1979; Caddy 2004), but information needed to parameterise those models is also lacking. Without species-specific survey and life history experiments, the existing management efforts in the North Pacific will not provide the information base for a quantitative stock assessment.

Current status

The difficulty in identifying octopus to species means that several diverse sub-populations must be managed as one unit. Even if a minimum size restriction is used to limit harvest to the best-documented species (*E. dofleini*), its biology and poor representation in the existing data collection system make it difficult to fit into the assessment framework currently used for groundfish. Current information is insufficient to model octopus with age-structured models and establishing harvest recommendations on a fraction of the natural mortality is also of questionable suitability. Mortality-based harvest models may be used for terminal spawners provided they are calculated on the non-spawning fraction of the population (Caddy 1983). However, the available data on which to estimate both the non-spawning biomass and the natural mortality for octopus in Alaska are flawed. The only option in the existing management system that is not based on biomass estimates, is one that is based on catch history; which is difficult to apply to a non-target species with little historical market value and minimal historical retention.

GOA skate complex

Background

Skates (family Rajidae) are cartilaginous fishes that are related to sharks. Within the family Rajidae, there are two genera, *Raja* and *Bathyraja*, with 7 and 13+ species, respectively, in the northeast Pacific (Love *et al.* 2005). The most common GOA skate species are the big skate *Raja binoculata* Girard, longnose skate *Raja rhina* Jordan & Gilbert, Aleutian skate *Bathyraja aleutica* (Gilbert), Bering skate *Bathyraja interrupta* (Gill & Townsend), and Alaska skate *Bathyraja parmifera* (Bean) (Gaichas *et al.* 2005). Between 1990 and 2003, skates were caught incidentally in both longline and trawl fisheries directed at Pacific halibut, *Hippoglossus stenolepis* Schmidt, and other groundfish. Skates became economically valuable in 2003 when the

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ex-vessel price for *R. rhina* and *R. binoculata* became equivalent to that of *Gadus macrocephalus* at approximately US \$0.55 kg^{-1}. Vessels began retaining and delivering these skates as a target species in federal waters partly because the market for skates had improved, and partly because catch of *G. macrocephalus* could be retained as bycatch in a skate (Other Species Complex) target fishery, even though directed fishing for cod was seasonally closed. The result was a dramatic increase in skate landings in 2003 (Figs 5 & 6).

The rapid development of a directed skate fishery presented both conservation concerns and assessment problems. From a conservation standpoint, skate life cycles involve relatively low fecundity, slow growth to large body sizes and dependence of population stability on high survival rates of a few, well-developed offspring (Moyle & Cech 1996). Skates have been classified as equilibrium life history strategists, with very low intrinsic rates of population increase; this implies that sustainable harvest is possible only at very low to moderate fishing mortality rates (King & McFarlane 2003). Therefore, the rapid increase in skate landings was cause for concern. The largest assessment problem was a lack of catch data; a secondary problem was the lack of biological information. Until 2004, catch of skates was reported within an aggregate Other Species Complex, so only direct observation of the fishery could provide the data necessary to estimate skate catch. Furthermore, limited port sampling suggested that the fishery was targeting large individuals, which were disproportionately the females of a single species in the complex (*R. binoculata*). However, a large proportion of directed skate fishing was prosecuted on vessels < 20 m in length, so there was no at-sea observer coverage of the fleet, which is used to estimate non-target catch for all other vessel classes in Alaska. These vessels delivered skates to plants that processed monthly volumes of catch that were also too low to require observer coverage, so there was no sampling of landed catch for species or size composition. Finally, substantial skate bycatch and discard was thought to have occurred in the unobserved *H. stenolepis* fishery. Therefore, this multi-species skate fishery developed without the appropriate monitoring needed to estimate total catch, catch by species, and size composition.

The initial stock assessment for GOA skates, developed in 2003, was in response to this developing target fishery and had as its highest priority the estimation of skate catch composition in both historical incidental

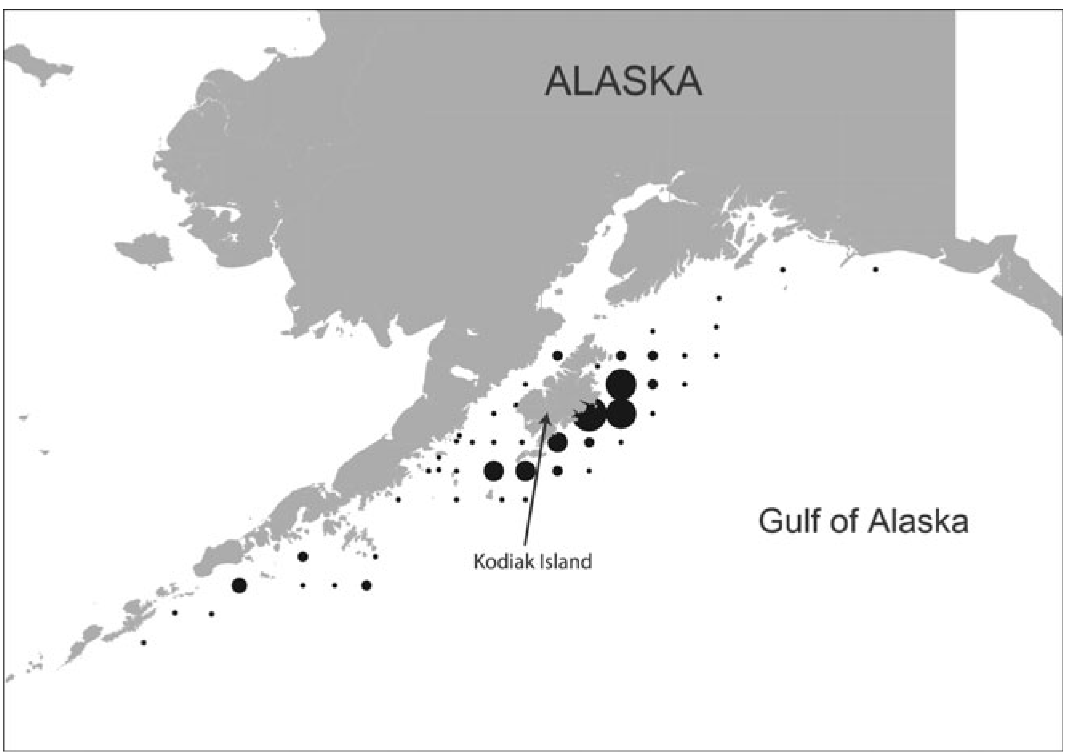

Figure 5. Skate catch in 2002 before the directed fishery rapidly developed, size of circle indicates relative catch.

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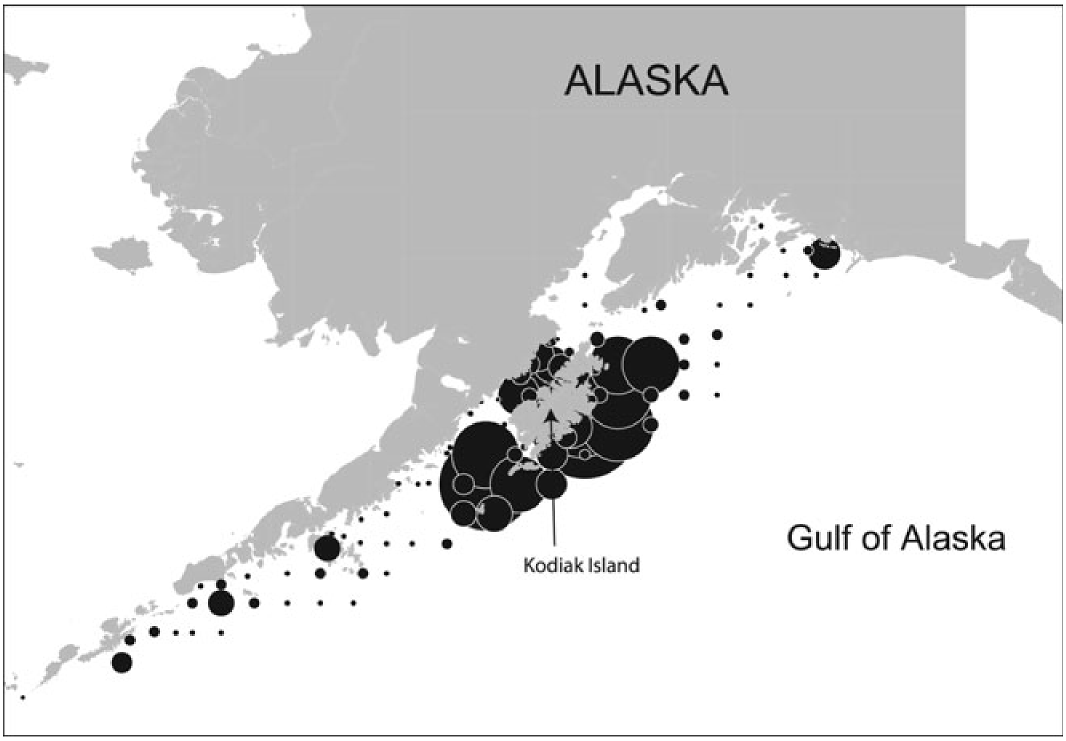

Figure 6. Skate catch in 2003 as the directed fishery rapidly developed, size of circle indicates relative catch.

catch and in the developing target fishery (Gaichas *et al.* 2003). Historical incidental catch for the aggregate GOA Skate Complex was previously estimated from groundfish observer data extrapolated to total catch records (Gaichas *et al.* 1999). The species composition within the aggregate skate catches was unknown because observers did not identify skates to species until 2003. Therefore, skate species composition in historical incidental catch was estimated using a spatial method (Gaichas *et al.* 2003, 2005). Skate species compositions from NMFS trawl survey locations were applied to observed fishery catches in those locations and summed across the entire area to estimate GOA skate catch by species from 1997–2002, providing a baseline for comparison with landings in the 2003 directed skate fishery. Skate catch by species from the 2003 directed landings was estimated from opportunistic port sampling of vessel deliveries in Kodiak, Alaska, by NMFS and Alaska Department of Fish and Game (ADF&G) personnel. A critical final component of catch was the unknown incidental catch in fisheries for *H. stenolepis*. To estimate this incidental catch, skate catch-per unit effort estimated from International Pacific Halibut Commission (IPHC) halibut longline surveys was applied to total effort in the *H. stenolepis* individual fishing quota (IFQ) fishery to estimate additional incidental catch of skates from 1997–2003. The magnitude of estimated skate incidental catch in the halibut fishery was similar to, or greater than, that estimated in groundfish fisheries (Gaichas *et al.* 2005), which suggested that inter-agency (IPHC-NMFS) coordination of skate management might be useful in the GOA.

Current status

GOA FMP Amendment 63 redefined the ABC, OFL and TAC setting process for GOA skate species in 2004 as a result of a developing target fishery for two skate species in 2003 (NPFMC 2003). This allowed the NPFMC to set the catch limits to prohibit target fisheries on these stocks until sufficient data are collected for improved stock assessment. While much of the skate assessment and management in response to this rapidly developed fishery happened in emergency reaction mode, there were efforts to manage skates separately prior to the development of the skate target fishery in 2003. An amendment to protect skates and sharks was proposed in 1999, and while this amendment was being developed the NPFMC recommended to NMFS that other species be placed on bycatch only status to prevent a directed fishery from developing in the interim. NMFS determined that it did not have regulatory authority for such an action,

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so an aggregate Other Species Complex TAC remained in place despite efforts to limit directed fisheries and develop more protective management within this category. Amendment 63 removed skates from the GOA Other Species Complex and allowed the Council to set specifications (OFLs, ABCs and TACs) for two skate species and an Other Skates Complex beginning in 2004.

Skate catch in the directed skate fishery declined considerably in 2004 and 2005, reportedly because of lower ex-vessel prices; but at least one participant in the 2003 fishery also reported a substantial drop in CPUE when attempting to target skates in 2004 (T. Pearson, personal communication). Gulf-wide trawl survey biomass for *R. binoculata* declined from 2003 through 2007 and biomass for *R. rhina* declined from 2005 to 2007 (Ormseth & Matta 2007). Skate catch, retention and sale continue in other GOA target fisheries, although the directed skate fishery has been closed since 2005 because of continued data limitations. Total skate catches in the groundfish fishery remain in the order of 2000–3000 t annually and ex-vessel prices for skates are increasing (J. Bonney 2007, personal communication). Some distinction of catch by species is now possible because species codes for *R. rhina and R. binoculata* were created in 2005. While catch accounting in the groundfish fishery has improved and management of *R. rhina and R. binoculata* quotas are now possible, considerable challenges remain for GOA skate assessment. These include estimation of bycatch in halibut IFQ fisheries, coordinating catch estimates between IPHC, ADF&G and NMFS, and obtaining important catch and life history information by species. The directed target fishery did not continue past its first year, partially because the NPFMC recommended a bycatch-only status for skates and a data collection programme to allow a directed commercial fishery. Skates continue to be retained and sold when caught incidentally in other target fisheries.

GOA forage fish

Background

While all fishes have important ecosystem roles, forage fish species in the Gulf of Alaska (GOA) serve as critical links between secondary production and higher trophic-level predators, including other fishes, seabirds and marine mammals. The list of managed species in the GOA FMP contains a Forage Fish Complex comprising over 50 diverse species occupying a variety of habitats (Conners & Guttormsen 2005). This group includes all GOA-inhabiting members of the families Osmeridae, Myctophidae, Bathylagidae, Ammodytidae, Trichodontidae, Pholidae, Stichaeidae, and Gonostomatidae, as well as the invertebrate order Euphausiacea (krill). Some members of this group tend to occupy shallower, nearshore habitats (e.g. capelin *Mallotus villosus* (Müller), an osmerid), while others occupy deep pelagic waters (e.g. Myctophidae and Bathylagidae). The most abundant species, and the most important species ecologically in the GOA, are capelin *M. villosus*, Pacific sand lance *Ammodytes hexapterus* (Pallas), and eulachon *Thaleichthys pacificus* (Richardson) (Aydin *et al.* 2007).

Mallotus villosus, *A. hexapterus*, and *T. pacificus*, like most of the Forage Fish Complex, serve as critical ecological links between zooplankton and higher trophic levels. All three species consume krill and calanoid copepods (Aydin *et al.* 2007), and are in turn eaten by larger fish, seabirds and marine mammals. For example, *M. villosus* is found in the diets of walleye pollock, *Theragra chalcogramma* (Pallas), and arrowtooth flounder, *Atheresthes stomias* (Jordan & Gilbert). *Ammodytes hexapterus* was the largest prey component by weight for puffins (*Fratercula* spp.) in the GOA and eastern Aleutian Islands in the early 1990s (Hatch & Sanger 1992). In the southeast Gulf of Alaska, Steller sea lions, *Eumetopias jubatus* (Schreber), rely on *T. pacificus* for much of their diet during the spring and their spatial distribution during that time is highly influenced by the timing and location of *T. pacificus* spawning runs (Womble *et al.* 2005). Forage fish are generally small in size, pelagic, patchily distributed and often occur in nearshore areas, and are thus not well sampled by the survey gears employed in Alaska. The assessment challenge, therefore, is to provide sufficient protection for forage fish species despite very poor data regarding abundance and life history parameters.

Forage fishes are generally not targeted by commercial fisheries in the North Pacific. Historically, *M. villosus* has been the target of large commercial fisheries in the Atlantic Ocean (Ushakov & Prozorkevich 2002), but similar fisheries did not develop in Alaska waters. A few small fisheries in Alaska state waters have targeted *T. pacificus,* an anadromous species, but it is an important subsistence food resource throughout the parts of coastal Alaska (Ormseth & Vollenweider 2007).

Obtaining reliable biomass estimate for GOA forage fishes is difficult. A useful example of the wide range of possible biomass estimates, depending on the estimation method, can be illustrated with *M. villosus*. In 2003, the bottom trawl survey conducted by the AFSC estimated its biomass of *M. villosus* in the GOA at 7588 t (Ormseth & Vollenweider 2007). An AFSC echo integration-trawl survey conducted in the same year

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estimated the biomass at 115 978 t (Guttormsen & Yasenak 2007). These widely varying estimates are both small relative to the results of a mass-balance ecosystem model that calculated 2 014 309 t of *M. villosus* must have been present in 2003 to account for the consumption by predators (S. Gaichas, personal communication).

Current status

Species within the Forage Fish Complex are currently protected in federal waters of Alaska by a ban on targeted commercial fishing and a maximum retention allowance (MRA). The ban on directed fishing also includes the sale, barter, trade or processing of forage fishes, except that forage fishes retained under the MRA may be processed into fishmeal. The MRA is set at 2% of the total weight of groundfish retained by a vessel. The advantages of this management approach are that new fisheries cannot be developed for forage fishes and that stringent rules are in place to limit the incidental catch of these species. The disadvantages are that the incidental catch of forage fish can increase with increased catches of target species, and that the relative impact of forage fish catches is hard to determine in the absence of reliable information on population sizes. Overall, the current management approach is probably the most effective one given the state of knowledge regarding this group of species.

Discussion

Mitigating fishing impacts on non-target species through a strong management framework that uses scientific analyses of available data, is an important aspect of an ecosystem approach to management that is designed to preserve and protect biodiversity and ecosystem structure and function (Hall & Mainprize 2004; Pikitch *et al.* 2004; Scandol *et al.* 2005; Smith *et al.* 2007). A challenge in achieving these goals is that the framework maintains healthy stocks for both target and non-target species, and allows for the development of new target fisheries. The framework used by the NPFMC, as shown by the case studies, provides guidance for how to obtain a catch limit for species or species complexes with varying amounts of data. Using similar reference points for managing both target and non-target species has been recommended by Hall and Mainprize (2004) and has proven successful in Alaska. Each case study reviewed obtained reference points that are also used for assessing target species, albeit with different data quality, for non-target species. These references points were obtained only when data quality was improved by identifying and recording to species data collected by fishery observers or on research surveys such as in the Sculpin Complex case study. Crowder and Murawski (1998) supported the need for monitoring programmes for incidentally caught, non-target species to determine detrimental impacts to the population and/or the ecosystem plus appropriate management strategies. Crowder and Murawski (1998) further highlighted the need for catch data and discard rates of species caught in targeted fisheries as a first step to adequately monitor non-target species. If a fishery observer programme and/or research surveys are non-existent or inadequate to collect data for potentially vulnerable non-target species, then creative strategies will need to be made to attain data that are critical in understanding the life history, distribution and abundance of the non-target species.

If reference points necessary for catch limits are unattainable, the management framework must be flexible to allow for alternative methods to both assess and manage data-poor species. The challenge with certain non-target species in Alaska, such as those in the Octopus Complex (unreliable catch estimates and biomass), is parallel to the challenges faced with managing many fisheries around the world, especially small-scale data-poor fisheries (Salas *et al.* 2007; Dowling *et al.* 2008). Alternatives that can be successful in achieving the goal of conserving fish populations range from using empirical indicators to creating closed areas to gear restrictions. Empirical indicators, such as life history characteristics (e.g. percentage of mature fish in catch), have been suggested as a way to monitor change in stock status for data-poor species (Froese 2004; Kelly & Codling 2006). King and McFarlane (2003) suggested management strategies that are customised to the respective life history strategy of a species or species group. For example, those species whose life history characteristics are described as slow-growing, long-lived, steady state population, but with variable recruitment (such as species in the Skates Complex), are termed periodic strategists. King and McFarlane (2003) suggested that an appropriate management strategy, in data-poor situations, for a periodic strategist could include using spatial refugia that would protect the older portion of the population. Methods for assessing extinction risk of a marine fish species also suggest using biological indicators as a first step, but then suggest further analysis to determine level of extinction risk accurately (Musick 1999; Dulvy *et al.* 2000). Furthermore, closed areas, marine refugia or marine protected areas have been suggested as alternative management strategies to

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quota management (e.g. Dugan & Davis 1993; Walters 1998), although complications arise when attempting to integrate their effectiveness into traditional stock assessments (Field *et al*. 2006). For example, the Octopus Complex does not have adequate catch and biomass data, but it is known that these animals use specific habitats, thus in theory, the suggestion of marine refugia may be a good precautionary tool. Convincing managers to use these alternative tools will require satisfactory data analyses to acquire indicators of how well those alternatives are working. Consequently, the need for these analyses would require data that are not necessarily easy or affordable to obtain, thus impeding management decisions.

Lessons learned from studying non-target species within a highly managed fishery in a developed country like the US are that management challenges still arise even if basic catch and biomass data exist. Although Alaska has a successful management system in operation, with annual catch limits (ACL) based on stock assessments for each target species and non-target species complex, new guidelines may be necessary to manage and monitor individual non-target, data-poor species adequately when a reliable ACL is not attainable or when an ACL is an insufficient management strategy. The GOA Skate Complex example demonstrated how simultaneously vulnerable and inflexible the current management system can be for species managed under the tier system, even when vulnerability was discussed in stock assessments prior to the directed fishery. Current guidance from the MSRA proposed NS1 guidelines is to have ACLs for all target and non-target species within a fishery (73 FR 32526), but ACLs may not always be attainable or appropriate. Therefore, management frameworks that allow flexibility when biological reference points are not practicably attainable should be used.

Considering that there are literally hundreds of non-target species in the FMPs in Alaska, some of which are still being described in the scientific literature, the challenge to monitor them adequately is formidable. For those species that are impacted by fishing, additional data will be required from both the commercial fleet and research surveys. For example, to understand the impact fishing activities have on non-target species will require extra effort from fishery observers to identify additional species. In addition, there will be a need to increase data collection from vessels that currently do not have adequate observer coverage. The concept of placing all data-poor non-target species on a bycatch-only and monitoring status without specifying catch limits was suggested and rejected in 2004 as an alternative approach to management of non-target species in Alaska (NPFMC 2004). In 2008, a group of NMFS scientists began development of technical guidance that would be used to evaluate the vulnerability to fishing of all stocks in U.S. federal fishery management plans. This document, when finished, will include modified risk assessment methods using productivity and susceptibility information that have been developed in Australia (Stobutzki *et al*. 2001; Astles *et al*. 2006). The goal is to avoid overfishing of highly vulnerable species by providing additional information so that managers can adequately manage these species.

Three case studies illustrating the challenges facing the assessment and management of non-target species in the Alaskan groundfish fisheries have been presented. In all cases the assessment authors were able to come up with a catch limit for management purposes. In Alaska, all non-target species assessment authors supplement their assessments with information that may be used to suggest whether alternative management strategies need consideration. What remains unclear is how to decide whether managing using a catch limit is insufficient protection for a species population and when additional management strategies should be implemented. Although catch and biomass trends have traditionally been used to determine what is thought to be the absolute health of a fished population, perhaps it is time to look beyond these data (which tend to be the most difficult and expensive to attain) towards other data that could determine or pre-determine the impacts of fishing on the populations of non-target species.

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