

Estimating Economic Effects of Fishery Management Measures Using Geospatial Methods

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Abstract

One of the main limitations of fishery management is that many routine data collection efforts are outpaced by evolving analytical needs. Examples include area-based management measures such as fishing closures and marine protected areas that are emerging in the context of ecosystem-based management. Typically, data collection efforts were not designed to address spatial issues. In the absence of comprehensive observer coverage or vessel monitoring systems, this creates a motivation for reinterpreting old data in new, spatially explicit ways. In this paper, we present a pilot geospatial relational framework for mining and integrating existing data developed for the West Coast of the United States (Washington, Oregon, and California), and discuss its applications to fishery management in the context of area-based management alternatives such as the groundfish closures instituted in 2002. Mining a variety of ecological, fishery dependent, and fishery independent databases, we built an extensive relational database—the Ocean Communities “3 E” ANalysis (OCEAN) framework—which allows the user to jointly consider ecological, economic, and equity (hence “3 E”) implications of marine management measures. We standardized the data, and conducted a meta-analysis on them, mapping trends over time and space in a geographic information system (GIS) that covers the length of the West Coast from Washington to California and covers the entire exclusive economic zone (EEZ). Using this framework, we analyzed various management scenarios

in terms of their effects on habitat areas and types, economic activity on shore, and likely implications for the fishing industry.

Introduction

Commercial fisheries off the coasts of Washington, Oregon, and California—as in other parts of the United States—are undergoing dramatic changes. Whether pelagic species, groundfish, or salmon, landings and revenues have been declining in most fisheries in the recent past. In the case of groundfish, the focus of this paper, commercial fishing for a complex of more than 80 species of soles, flounders, rockfish, sablefish, and whiting that are jointly managed by the Pacific Fishery Management Council (PFMC) dates back to the nineteenth century. The fishery has been prosecuted with gear types including hook and line, pots, traps, and trawl nets. After a period of expansion following the passage of the Magnuson-Stevens Fisheries Conservation and Management Act of 1976 (MSFCMA) and the subsequent “Americanization,” landings of groundfish have declined over the past 20 years. Some species have declined to levels that trigger stringent rebuilding plans and bycatch avoidance measures, affecting the rest of the groundfish management complex.

The fishery is increasingly managed on the basis of time and area closures designed to minimize bycatch and allow for rebuilding of threatened species. While potentially better aligned with ecosystem mandates for marine resource management (EPAP 1999, NRC 2001), the comparatively new class of spatio-temporal management measures such as 2002 in-season closures poses considerable challenges to the management process. Specifically, fishery dependent and independent data that have been collected on the West Coast for over 20 years cannot be directly interpreted to analyze alternative spatiotemporal management measures or their impacts on the economic well-being of fishing communities.

Recognizing these limitations, a recent National Academy study, in reference to legally mandated essential fish habitat (EFH) assessments and management tools such as marine protected areas, notes that “NMFS [now NOAA Fisheries] and its partner agencies should integrate existing data . . . to provide geographic databases for major fishing grounds” (NRC 2002, p. 3). In the remainder of this paper we outline a spatial framework for linking ecological, fisheries, and socioeconomic information that utilizes existing, readily available data. We discuss the application of this approach to fishery management issues on the West Coast of the United States.

Materials and methods

The OCEAN framework

Conceptually, the Ocean Communities Economic/Ecological/Equity Analysis (OCEAN) framework is a multilayered information system comprising geographic and other data in a set of linked, “smart” maps—maps with attached databases that relate many different data sources to each other and facilitate their manipulation and analysis at the landscape (or, in this case, oceanscape) scale. It is rooted in the growing literature of marine geographic information systems (GIS) that are being developed to address a host of oceanographic, coastal, and fisheries issues and problems (Kruse et al. 2001, Valavanis 2002, Breman 2002, Green and King 2003). OCEAN is essentially a meta-analytical tool for combining a range of data, using a relational database architecture and spatial analysis as the common currency.

Analytically, the OCEAN approach centers on the spatial association of a heterogeneous set of data. This kind of analysis has been used in other marine applications of GIS, e.g., to assess the location of fishing effort close to shore (Caddy and Carocci 1999) or to detect trends in global fishery statistics (Watson and Pauly 2001). The OCEAN approach operates at an intermediate, regional scale, with explicit consideration of the socioeconomic impacts in coastal communities. The system can be queried from within any one data layer, e.g., to find particular vessels or gear groups fishing in a habitat of interest, or to generate the vessel revenues associated with a particular species. Information can be manipulated both in database formats and map-based user interfaces, and results are summarized in map formats.

The centerpiece of this approach is the modeling of data that are already available in spatially explicit formats, and combining them with other, newly spatially interpreted, information. The challenge was to organize data from diverse sources, in diverse formats, and of varying quality, and to integrate them into a single framework. We began work on OCEAN by reviewing existing sources of data and compiling them into one relational database. Where necessary, we built new models to spatially interpret data, especially those pertaining to the distribution of fishing effort. Combining bathymetry and habitat information with fishing effort and species distributions then formed the basis for analyzing where vessels fish by gear type and target species. To this we added an economic model for assessing the relative socioeconomic impacts of different management scenarios. We present here results from an analysis of area-based management measures using “version 1.0” of OCEAN.

Data sources and their limitations

We obtained 14 years of data on landings, revenues, and vessels from the Pacific Fisheries Information Network (PacFIN), which stores and compiles

fishery-dependent data that are routinely collected by the three states in our study area (Washington, Oregon, and California) (Sampson and Crone 1997). Data were summarized to individual vessels by port, gear, species, and year for all vessels reporting groundfish landings. The availability and quality of data for different fishing sectors vary considerably. The trawl fishery is documented the best, with at-sea logbooks augmenting the information on catch and landings that is reported port-side in the landing tickets. Trawl logbooks are spatially explicit, with trawl set points recorded for individual trawls (typically referenced by 10-minute blocks). Trawl duration is also recorded, thus providing a measure of effort.

The trawl logbook data had two major limitations. First, although skippers record trawl endpoints, these are not transcribed into the PacFIN database. Since there is as yet no comprehensive vessel monitoring system in place on the West Coast, estimating the precise extent of trawl activity remains rather difficult. To remedy this, we modeled tow tracks based on trawl set points and trawl duration. Essentially, we constrained vectors of possible trawl directions by using habitat and bathymetric consideration for each recorded tow. The result is a density map of probable tow tracks. Second, although the same vessel identifiers are used in both data collection efforts, there remain considerable gaps between the logbook and landing receipts record sets (Fox and Starr 1996, Sampson and Crone 1997). For our analysis, we used a record set provided by PacFIN in which the records were already matched up, thus subsuming any associated uncertainty.

No such logbooks exist for the fixed gear sectors of the fishery, making landing receipts the only source of information. These are less spatially explicit and typically contain no measure of fishing intensity or effort. With the exception of California, where all landings are recorded in 10 minute blocks, the spatial unit of PacFIN landing receipts are statistical areas defined by the now defunct International North Pacific Fisheries Commission (INPFC). There are only twelve INPFC areas for the entire West Coast from Cape Flattery in Washington to the Mexican border, each covering thousands of square miles. We developed an iterative algorithm (described below), drawing on all the data assembled in OCEAN to make the landing receipts more spatially explicit. This, in turn, formed the basis for considering the socioeconomic implications of management measures such as the in-season shelf closure, which affect vessels that used to fish in the now closed areas.

Bathymetry and other data on oceanographic characteristics were obtained from the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), and state agencies such as the California Department of Fish and Game. One key component for ecosystem management is habitat and the consideration of the impact of fishing activities on different parts of the seafloor. The continental shelf in our study area has been the subject of considerable habitat

mapping efforts, such as the USGS habitat GIS for the Monterey Bay National Marine Sanctuary (Wong and Eittreim 2001). Using known habitat associations for various fish species, as well as the depth constraints on particular types of fishing gear, habitat data can be used to relate fishing effort to particular areas.

Trawl surveys conducted by NOAA Fisheries over the past 25 years are a major source of fishery-independent data. We obtained all available years of shelf and slope surveys from the NOAA Alaska Fisheries Science Center, 1977-2001. NOAA research vessels using trawl gear record the total number, size and age distribution, and weight of fish sampled along fixed transects, typically during the summer months (Lauth 2000, Weinberg et al. 2002). Because of the consistency of the sampling protocol the trawl surveys generate a comprehensive picture of species abundance, at least along the trawl transects and during the sampling period. Species and abundance (number of fish per species) are recorded for each trawl start point. We extracted individual records of species targeted in the commercial fishery from the surveys, normalized these by total effort, and generated species-specific density maps. Following an approach developed by NOAA's Biogeography Group (NOAA 2002), we summarized these to 9 km by 9 km analysis units, and derived single, cumulative species distribution maps for each target species.

The final component of OCEAN concerns the linkage between fishing activity and coastal communities. The obvious points of contact are the landing ports, where vessels sell their catch to fish buyers and processors. Together with other marine services and businesses, processing is a major contributor to income generated in coastal communities. This aspect of socioeconomic impacts is already captured in a regional input-output model used by the PFMC to assess the economic impacts of fishery policy (Jensen 1996, 1998). The fisheries economic assessment model (FEAM) belongs to a class of regional input-output models that treat the economic activity in a region as a set of interconnected sectors (Hewings 1985). Each dollar generated in one sector has a "multiplier effect" because it generates economic activity in other sectors. For example, fish are landed and the vessel is paid a price per pound for its catch. Out of this ex vessel revenue, crew shares, maintenance and moorage costs, and other expenses are paid, which in turn generate personal income, and revenues for the port district and other marine-related businesses. The FEAM estimates these effects for the two primary sectors affected by fishing activity, i.e., harvesters (fishermen and their families) and processors. We summarized these model outputs in a set of spreadsheets, which we integrated into OCEAN. This allowed us to consider the income impacts of changes in landings in a port resulting from particular management scenarios.

A key limitation of the FEAM analysis is that it is static in nature and provides only an incomplete snapshot in time. It is premised on the land-

ings and revenues generated by the fishing fleet, but is silent on alternative sources of revenues in coastal communities such as tourism. Unlike other regional input-output models, FEAM is not designed to assess employment effects. Furthermore, a host of considerations beyond economic impacts are of importance to coastal communities and managers, but they are not yet routinely assessed. For example, the lifestyle aspects of fishing communities are important (The H. John Heinz III Center for Science Economics and the Environment, [Hanna et al, 2000]), as are concerns about the social and cultural resilience of ports and towns in response to the structural changes in the fishery (Langdon-Pollock 2002). By way of addressing these concerns, and to lay the groundwork for more in-depth analysis of coastal communities in future applications of OCEAN, we incorporated census statistics as well as qualitative information derived from port visits and interviews.

New tricks: methods for modeling fishing effort

To illustrate the spatial modeling conducted in OCEAN, consider the challenges inherent in determining the spatial extent of trawl and fixed gear fisheries, i.e., the distribution of fishing effort on the fishing grounds. This is key, for example, for assessing the socioeconomic implications of reducing certain sectors of the fleet, assessing the effects of area closures, or for determining the likely habitat interactions of particular gear types. In the absence of a comprehensive observer program (summarized data from the first year of west coast observer program are posted on the Northwest Fisheries Science Center's Web site, but do not provide any insights into the location of the fleet) or vessel monitoring systems, there is considerable uncertainty about where vessels using gear types other than trawl gear are fishing.

The OCEAN effort submodel essentially consists of a sequence of steps, programmed in ArcINFO, which successively constrain each landing record and subsequently apportion catch and revenue to equal area analysis units (9 km by 9 km blocks) based on probability of fishing activity in an area. In contrast to multivariate analysis used in terrestrial applications, which generally predicts what happens in a particular location (e.g., Hargrove and Hoffman 2003), we try to predict the location for known entities. The following steps characterize this process; Fig. 1 shows a flow chart of the model:

1. Each PacFIN record contains information on the gear used, species caught, landing port, vessel information, and one of twelve statistical management areas where the catch originated.
2. Impose a maximum range from the landing port that a vessel is likely to have fished, given its length and gear type used. This is

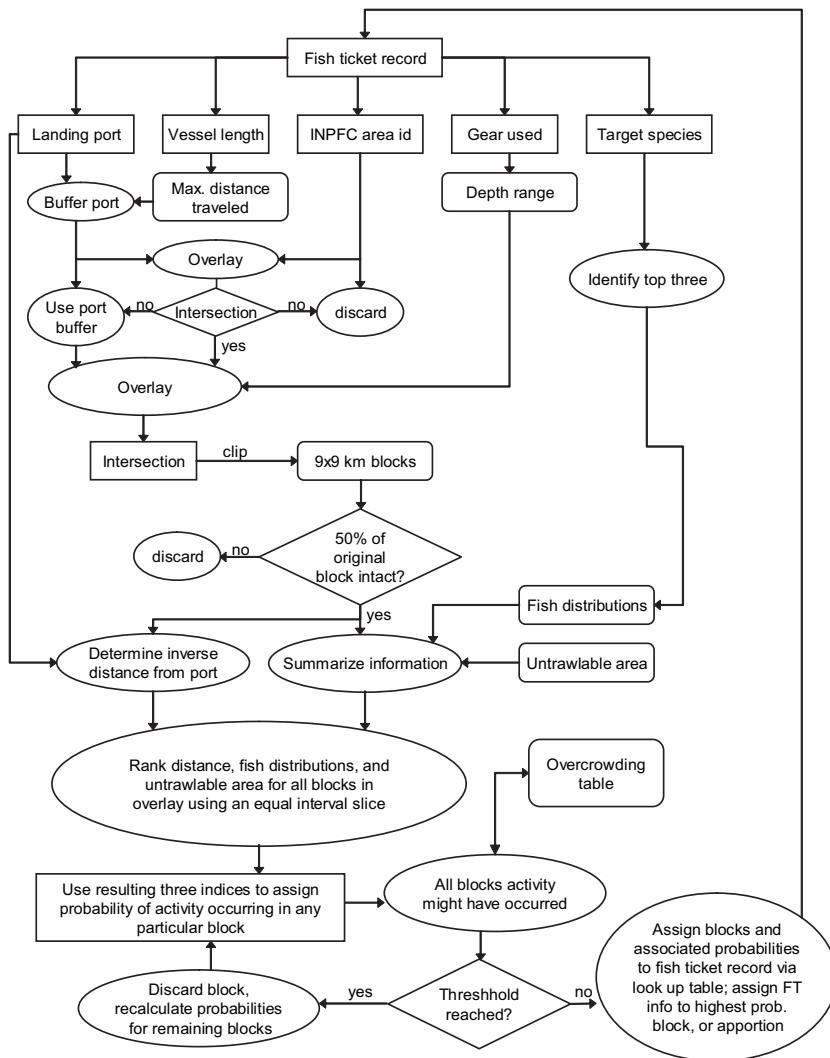


Figure 1. Commercial fishing effort model flow chart.

currently derived from expert witness testimonies, pending more formal studies of fishing behavior on the West Coast.

3. Impose depth restrictions on fishing gear used and target species. There are limits to the depth from which west coast trawlers can haul their nets, or in what depth various fixed gear types are used; similarly, different species of fish have known ranges of bathymetric associations.
4. Compare this to the species distribution densities derived from the fishery-independent surveys. Some areas are associated with higher frequencies of the target species in question, making it more likely that a fishing vessel would have gone there for its catch.
5. Within that maximum range, weight the species density clusters inversely by distance from port. This is a “friction of distance” idea: because travel is costly, vessels tend to fish closer to port even if they are slightly less likely to encounter the target species.
6. Impose habitat restrictions on fishing gear used. Trawlers do not operate in high relief areas, while these same areas tend to be frequented differentially by vessels using hook and line gear.
7. Apportion pounds caught and associated revenue from fish tickets. This can be done either deterministically, associating the entire catch and revenues with the block that has the highest likelihood of fishing having occurred there; or probabilistically, apportioning catch and revenues to fishing blocks within the maximum range based on probabilities derived from distance from port, targeted species densities, habitat restrictions, and previous activity.
8. Repeat for all records and map the resulting distribution of fishing activity. In principle, this can be normalized by number of records associated with an area, or—in the case of trawlers—number and duration of tows made there, to provide a measure of effort.

The maps resulting from this algorithm are probability surfaces of the distribution of fishing effort and the associated catches and revenues (see Fig. 2). The results discussed here are derived from an earlier, deterministic version of the model. We discuss the probabilistic model and its sensitivity to various assumptions in a forthcoming publication (Scholz et al. 2005). In general, however, it is most sensitive to assumptions about the maximum range of vessels from port and about the associations of gear types with particular habitats, as well as to the weight given to the overcrowding parameter. We are in the process of further refining this approach.

It is important to note that the OCEAN effort model constitutes a spatial re-interpretation of historic data. While it is conceivable to turn

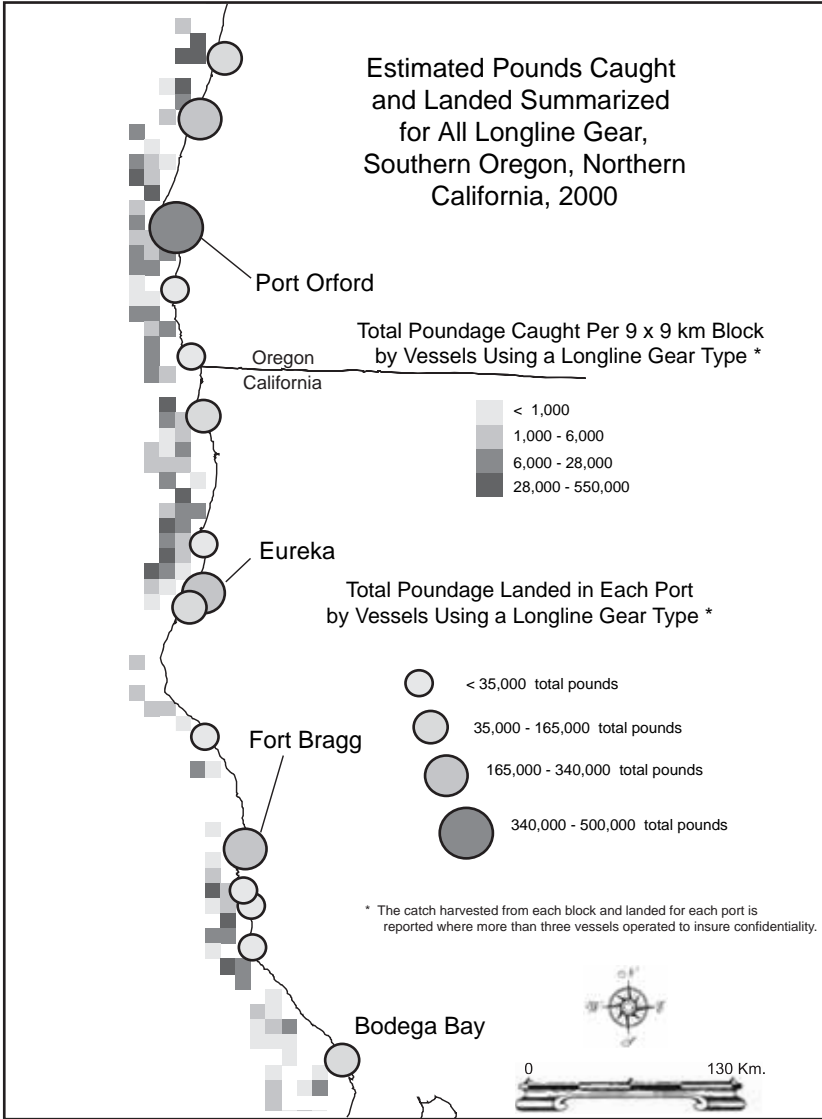


Figure 2. Sample output of commercial fishing effort model.

this into a predictive model, a major confounder lies in the absence of behavioral models of the fishery. In other words, there are few, if any, known rules that describe fleet behavior, and most economic models that attempt this are based on simplistic assumptions about rational actors and individual profit maximizing considerations.

Results: OCEAN applications to fishery management

A key characteristic of OCEAN is that it links fishing activities on the continental shelf to particular gear types, catches, and revenues, and thus to ports. To illustrate the utility of this feature for fishery management, consider the recent shelf closures put into effect on the West Coast of the United States. Implicit in area-based management measures is a displacement effect on fishing vessels. Depending on the size and depth covered by closure areas, some vessels may be induced to exit the fishery.

For example, the 2002 in-season shelf closures affected depths between 100 and 250 fathoms; fishing farther offshore, to the west of the closure area, is only feasible for a subset of the fishing fleet—vessels with sufficiently large engines and deepwater gear. Not all of the vessels that fished in the closure area will successfully relocate closer inshore. As an initial estimate of the potential displacement effect, in economic terms, we considered the shelf closures relative to the landings, revenues, and income generated inside it in the most recent year prior to the closure for which data were available to us, 2000. Figure 3 shows the extent of the shelf closure and the poundage caught there in 2000 by the west coast trawl fishery.

Using the 2000 fleet and effort distributions as a baseline, we identified the number and types (by gear, size, and species targeted) of vessels that likely fished in the closure area. Assuming that the same vessels would have fished there in 2002, we then computed an estimate of the coastwide income impacts associated with the landings initially lost due to the closure. Since this is a static analysis, we did not consider the adaptive effects, and consequently the estimates constitute the upper bound of the wealth effect. For the total coast, with landings worth (in 2000) \$137 million, the income impacts generated by landings outside the closure area amount to around US\$115 million, and thus the closure potentially results in lost income on the order of US\$22 million if vessels were permanently displaced. More interesting, the estimated effects of the shelf closure vary along the coast, since fishing in the shelf areas is of varying importance for different ports, gear groups, and fishing vessels. The estimated income effect of the closure, therefore, varies accordingly, as shown in Fig. 4.

From San Diego in the south to northern Puget Sound on the U.S.–Canadian border, there are significant differences in the degree to which

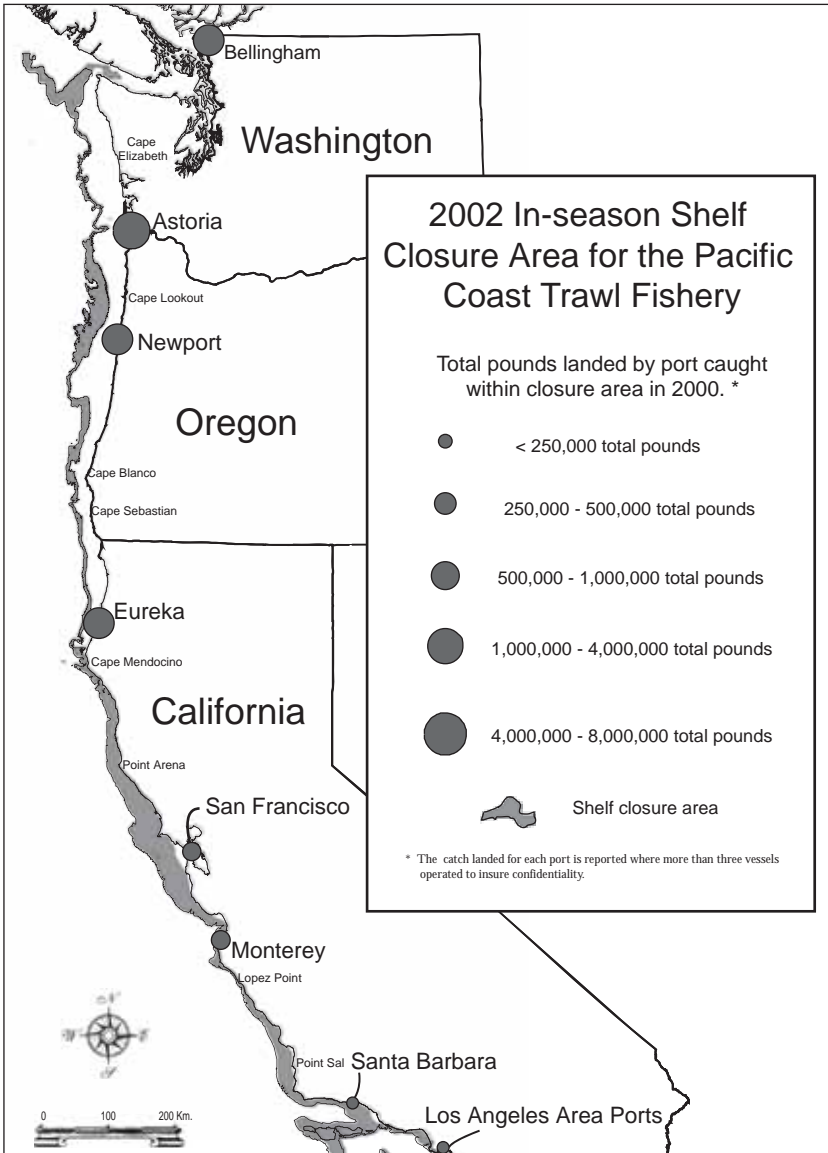


Figure 3. Extent of shelf closure and poundage of groundfish landed by the west coast trawl fishery in 2000 that originated there.

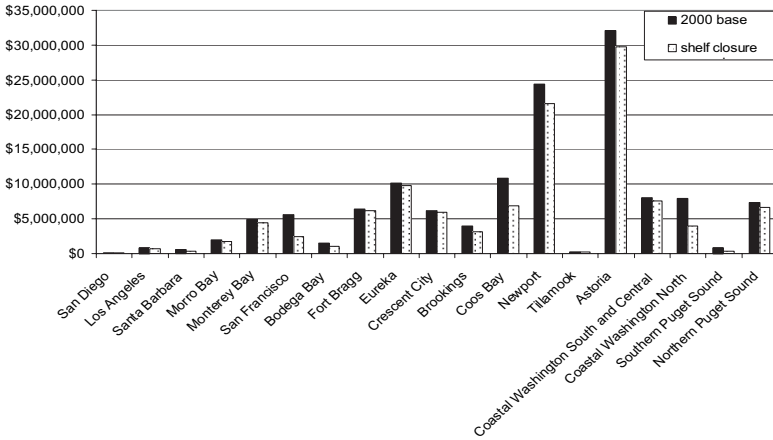


Figure 4. Estimated processor and harvester income from groundfish landings by port group before and after the 2002 shelf closure.

port groups were estimated to have been affected by the shelf closure. While ports farther north generally have higher total groundfish landings, the estimated income effect of the shelf closure area varies considerably relative to other port groups. For example, while Eureka and Crescent City appear relatively unaffected, Newport and Astoria were estimated to experience a larger impact, and a more pronounced income effect is estimated for Coos Bay and northern coastal Washington. These results are a reflection of the regional fishing patterns: the shelf is steeper near Crescent City, making for a narrower shelf closure area, which consequently is not as significant for the local fleet as the shelf off Newport and Astoria.

This is further illustrated by Fig. 5, which shows the percentage of landings and revenues derived from the shelf closure area. Although total income derived from groundfish in southern California ports between San Diego and Morro Bay is small (see base amounts in Fig. 4), the reliance on shelf closure areas can be quite large, e.g., accounting for over 50% of groundfish landings and revenues in Santa Barbara. In other words, what fishing there is for groundfish is highly dependent on the closed areas, which make up much of the area around the historically productive Channel Islands.

Another important aspect of the geographical difference of reliance on the shelf closure areas emerges from the difference between landings and revenues. For example, less than 5% of groundfish landings in Newport are estimated to come from the shelf, but these account for almost

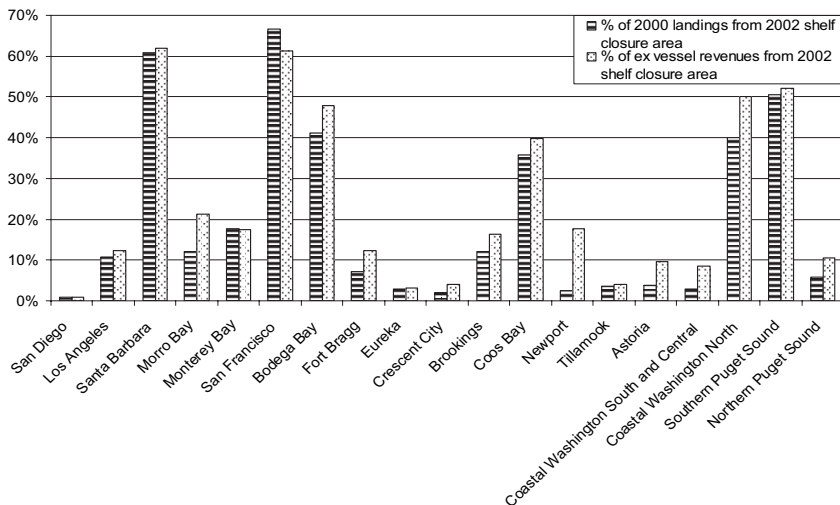


Figure 5. Commercial fishery landings and ex vessel revenues from inside the 2002 shelf closure area.

20% in ex vessel revenues in this port. This suggests that the shelf closure areas yield relatively more valuable species than other fishing grounds. Again, this illustrates the geographic differences of the fishery’s reliance on the shelf closure area.

Conclusions

The analysis and results presented here are illustrative of the kind of assessments that can be conducted with a spatially integrated analytical framework such as OCEAN. The OCEAN approach makes use of currently available data and harnesses them in a framework that can be accessed by decision-makers and communities directly. By linking a GIS to fishery data (which, with the advent of electronic logbooks, could conceivably be accessed in real time) and economic impact models, we were able to generate estimates of the effects of fishery management measures, in this case area closures. Other measures that could be analyzed using this framework are fleet restructuring mechanisms such as vessel buybacks or individual quota systems, and measures designed to protect essential fish habitat or reduce bycatch.

Our analysis suggests that geography matters: scenarios have location-specific and differential effects in different parts of the coast, on differently composed fleets (by size and gear-types), and by the relative

reliance on particular species or fishing grounds. We are cautiously optimistic that, as spatially explicit models such as OCEAN become more commonplace in fishery management, decision-makers and stakeholders will seize upon them for investigating synergistic effects, e.g., between habitat protection and increasing the economic feasibility of the fleet.

While there are many conceivable extensions of this approach to predictive modeling, an immediate benefit of OCEAN is that it makes visible and spatially interprets the existing data, and thus helps identify gaps and problems with current information sources. In particular, it remains to be seen if the spatial interpretation of historical landing receipts can be validated using the forthcoming observer data on the West Coast or a future vessel monitoring system.

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Sportfishing Catch and Harvest of Pacific Halibut (*Hippoglossus stenolepis*) in Glacier Bay National Park

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Abstract

Actions taken by a manager to reduce or increase allowable harvest are legitimized through the collection of accurate fishery harvest information. In many cases the fishery is large and/or remote, contains a large diversity of users, lacks historical data, or is subject to large reporting errors that hamper collection efforts and decrease the accuracy and precision of estimates. These data limited situations require a holistic approach when surveys are being designed. Glacier Bay National Park

presents a data limited situation in that the existing survey data does not enable managers to estimate sportfish catch and harvest of Pacific halibut (*Hippoglossus stenolepis*) in park waters. This paper focuses on a combination of survey methodologies used to create a fishery survey program in Glacier Bay National Park to estimate halibut harvest and catch by sport anglers. Methods employed were a creel survey, aerial survey, mail survey, telephone survey, and boat observations. We found that the mail and telephone surveys provided the most precise estimates of halibut catch and harvest, while the creel and aerial surveys provided the least precise estimates. We also found that anglers included in the mail and telephone surveys accounted for the majority of the sportfish halibut catch and harvest in Glacier Bay proper and areas directly adjacent to Glacier Bay proper. Moreover, data from the aerial survey suggest that anglers misreported halibut catch and harvest levels in the creel survey. This paper is a contribution to a general methodology that could be employed in the management of the Glacier Bay National Park sportfishery. The framework created in this paper is flexible enough to be of value in the management of sport fisheries in other locations as well.

Introduction

Fishery managers are faced with the difficult task of modifying human behavior through regulations that control fishery harvest (Cicin-Sain and Knecht 2000). Actions taken by a manager to reduce or increase allowable harvest are legitimized through the collection of accurate fishery harvest information. In many cases the fishery is large and/or remote, contains a large diversity of users, lacks historical data, or is subject to large reporting errors that hamper collection efforts and decrease the precision of estimates (Crosby 1995, Crosby et al. 2000). These data limited situations require a holistic approach when surveys are being designed. Distinct attributes such as access points, level of use, political climate, and user group needs should be incorporated into a survey design (Pollock et al. 1994).

Mail and logbook survey programs implemented by Glacier Bay National Park (GBNP) and the Alaska Department of Fish and Game (ADFG) provide little to no information for sportfishing related catch, harvest, and effort for Pacific halibut (*Hippoglossus stenolepis*) occurring in park waters by user group (private and charter) and point of origin (Gustavus or Bartlett Cove). These data limited characteristics of GBNP have prompted resource managers to assess halibut sportfishing pressure within GBNP.

This study provides baseline data in GBNP for halibut catch, harvest, and effort by user group and port of origin. This study also outlines methodologies that can be applied to other recreational fisheries that have diverse user groups, are situated near marine protected areas, have



Figure 1. Map showing fishing areas covered by the creel, aerial, telephone, and mail surveys. Mail and telephone surveys covered the entire Glacier Bay.

complex licensing or permitting requirements, and/or have little or no baseline monitoring data.

Background

Glacier Bay National Park is located approximately 90 miles west of Juneau, Alaska, in remote northern Southeast Alaska. Marine waters in GBNP encompass 243,339 km² and include Glacier Bay proper, waters within the Cross Sound/Icy Straight region, and the Outer Coast from Cross Sound to Sea Otter Creek north of Cape Fairweather (Fig. 1). Approximately 45% of GBNP marine waters (110,000 km²) exist outside Glacier Bay proper. The Glacier Bay area is a popular sportfishing destination with halibut, salmon (*Oncorhynchus* spp.), and rockfish (*Sebastes* spp.) being the primary target species. Sportfishing in the area is focused on the arrival of anadromous fish and the movement of halibut into the area during the

summer months (May-September). The majority of sportfishing in the region occurs May 15-September 15. Fishing effort originates from three locations: Gustavus, Elfin Cove, and Bartlett Cove. There are four primary user groups in the sportfishery: marine anglers based out of Gustavus, Elfin Cove, and Bartlett Cove; and marine anglers entering Glacier Bay proper during a special GBNP permitting season (June 1-August 31). Sportfishing charters operate from the communities of Gustavus and Elfin Cove.

Vessel activity in the bay proper is further restricted by a limit on the total number of boats that are allowed to reside in the bay per day. The permitting system consists of a local permit and general permit. Local permits are issued to private marine boaters originating from the communities of Gustavus and Bartlett Cove. General permits are issued to private boaters (including locals from Gustavus and Bartlett Cove) entering Glacier Bay proper.

Charter businesses are allowed to operate within GBNP through a separate permitting system. A GBNP concessionaires permit or incidental business permit is required for sportfishing charters operating within park waters.

Private and charter recreational fishing activity (effort, catch, harvest) for anglers in the greater Glacier Bay region is documented by state and park sponsored programs. These programs are composed of a charter logbook program implemented by GBNP (since 1995) and a mail-out survey (Statewide Harvest Survey: SWHS) administered by ADFG.

The SWHS survey is not useful for understanding sportfishing activity relative to GBNP boundaries because it fails to delineate catch, harvest, and effort occurring within park boundaries. Natural Resource Management Guidelines for GBNP require that "fishing activities must be managed through . . . a harvest reporting system which addresses harvests within park boundaries." Similarly, the GBNP logbook program has a limited ability to assess fishing activity relative to park boundaries. The logbook program is for permitted charter anglers and thus excludes private anglers, non-permitted charter anglers, and charter anglers fishing illegally. The logbook program also may not accurately reflect charter fishing activity in GBNP, as it relies on self-reporting and has not been validated.

Project goals

The primary goal of this study is to estimate harvest and catch of sport-caught halibut in marine waters directly adjacent to and within Glacier Bay proper. Marine waters adjacent to Glacier Bay proper encompass an area between northeastern Lemesurier Island, Pt. Carolus, Pt. Gustavus, and approximately 5 km south of the GBNP boundary (Fig. 1). Three objectives are discussed in context with the primary goal: (1) provide halibut catch and harvest estimates for each survey method; (2) determine the precision of each survey method; (3) evaluate the accuracy of creel

survey responses using an aerial survey. The final section of this paper provides a brief discussion on how this study improves the data limited situation in GBNP.

Survey methods described in this paper are also used to obtain estimates for rockfish, salmon, and lingcod (*Ophiodon elongatus*). For the purpose of this paper, only results for halibut are presented.

Methods

The complexity of the permitting system, remote nature of the fishery, and disparate use levels between charter and private anglers required a multifaceted survey program. Four survey methods were used to obtain an estimate of halibut catch and harvest in GBNP waters: (1) a creel survey at the Gustavus dock for private and charter anglers; (2) a mail-out survey for general permitted anglers; (3) an offsite telephone survey for local permitted boaters; and (4) an aerial survey of charter boats that were fishing in park waters directly adjacent to Glacier Bay proper. The following sections discuss each method in detail.

Gustavus creel survey

Anglers fishing in marine waters from a boat were intercepted at their landing site (dock) after their fishing trip was completed. Catch, harvest, and effort information relative to the location of fishing (ADFG statistical area and GBNP specific statistical areas), type of fishing being conducted (bottomfishing or salmon), and fishing trip type (private or charter) were collected at the Gustavus dock. Creel surveys were conducted from June 1 to September 15, 2003.

Although the Gustavus creel survey covered a wide geographic area and involved multiple species, this method is focused only on Glacier Bay proper, marine water adjacent to Glacier Bay proper, and fishing activity relevant to halibut.

Estimates of catch and harvest for halibut in the Gustavus fishery were made between June 1 and September 15, 2003, using a two-stage, stratified random design (Cochran 1977). The first stage consisted of the days sampled and the second stage was composed of boating parties. A single access point was used on a daily basis by private and charter boats in Gustavus. A pilot study showed that approximately 90% of the daily activity occurred between 1200 and 1900 hours (Gasper et al. 2004). Sampling effort was limited to that time period because it captured the majority of anglers completing their fishing activities.

Strata were divided into weekend and weekday strata due to potential differences in use that result from angler work schedules. All days within the weekend stratum were sampled and three to five days were randomly sampled during the weekday stratum. A census was attempted for all boating parties within a sampling period. To insure all parties who

fished were counted, we asked parties who refused an interview if they had fished.

Analysis

The following equations were used to estimate catch and harvest by substituting the appropriate statistic. Equations 1.1-1.8 were obtained from Bernard et al. (1998) and Cochran (1977). Calculations of the fishery statistic (\hat{Y}_{hi}) on day i within stratum h were made for a user type and location as

$$\hat{Y}_{hi} = M_{hi} \bar{y}_{hi} \quad (1.1)$$

where:

M_{hi} = the count of anglers during day i in stratum h , and

\bar{y}_{hi} = the mean statistic (catch or harvest) of interviewed anglers on the i^{th} day in the h^{th} stratum (weekend or weekday).

The estimate of the fishery statistic (catch or harvest) for stratum h is (Bernard et al. 1998)

$$\hat{Y}_h = D_h \frac{\sum_{i=1}^{d_h} \hat{Y}_{hi}}{d_h} \quad (1.2)$$

where:

D_h = the number of days in the sampling frame,

d_h = the number of days sampled, and

\hat{Y}_h = the total statistic (catch or harvest) estimate for stratum h .

An estimate of the variance for catch or harvest is:

$$\text{Var}(\hat{Y}_h) = (1 - f_{1h}) D_h^2 \frac{S_{1h}^2}{d_h} + f_{1h}^{-1} \sum_{i=1}^{d_h} M_{hi}^2 (1 - f_{2hi}) \frac{S_{2hi}^2}{m_{hi}} \quad (1.3)$$

where:

$$f_{1h} = \frac{d_h}{D_h}, \quad (1.4)$$

$$f_{2hi} = \frac{m_{hi}}{M_{hi}}, \quad (1.5)$$

m_{hi} = the total number of boating parties interviewed in stratum h on day i , and

M_{hi} = the total number of boating parties counted in stratum h on day i .

$$S_{2hi}^2 = \frac{\sum_{j=1}^{m_{hi}} (y_{hij} - \bar{y}_{hi})^2}{m_{hi} - 1}, \quad (1.6)$$

y_{hij} = the fishery statistic (catch or harvest) for boating party j on day i in stratum h ,

$$S_{1h}^2 = \frac{\sum_{i=1}^{d_h} (\hat{Y}_{hi} - \hat{Y}_h)^2}{d_h - 1}, \quad \text{and} \quad (1.7)$$

\hat{Y}_h = the statistic (catch or harvest) for day i in stratum h . Note: $Y_{hi} = \sum y_{hij}$ when $M_{hi} = m_{hi}$.

The mean fishery statistic parameter estimate (catch or harvest) is

$$\hat{Y}_h = \frac{\sum_{i=1}^{d_h} \hat{Y}_{hi}}{d_h}. \quad (1.8)$$

Aerial survey

Aerial surveys were used in conjunction with the Gustavus creel survey to estimate halibut catch and effort for GBNP waters between Pt. Gustavus and Pt. Corolus. Aerial surveys were used to estimate the number of boats fishing within park waters and the creel census was used to model catch or harvest based on effort (number of boats). Aerial surveys were conducted between June 16 and September 15, 2003. A total of 46 days were surveyed out of the 106 day sampling frame.

An estimate for the number of boats residing within GBNP using observations from the aerial survey was based on a two-stage randomly stratified design. The first stage, based on days sampled, was stratified into weekend and weekday sampling periods. The second stage, based on the time of day sampled, was stratified into equally sized morning and afternoon periods: 700-1200 for morning periods and 1201-1900 for

afternoon periods. Two to four weekdays and one or two weekend days were randomly selected for each week surveyed. A census of all boats was assumed during each survey period because of the small size of the survey area, short flight duration across the sampling area (<5 min), and positive identification of boats using digital photography.

Charter vessels from Gustavus were visually identified using the five-digit Commercial Fishery Entry Commission (CFEC) vessel license number visible on a vessel's side, the vessel's name, or by comparison with photographs of vessels residing at the Gustavus dock. A unique characteristic such as gear configuration, boat color, motor configuration, or navigational equipment was also used to identify a digitally recorded vessel license number. It was generally easy to identify charter vessels from Gustavus because they are homogeneous in style and length, ranging from 24 to 28 feet and always having an enclosed cabin.

Several criteria were used to identify charter vessel activity: (1) visual conformation of fishing gear (i.e., rods and reels, rod holders, and downriggers, etc.) being used; (2) the presence of several (> 2) anglers fishing actively on deck; and (3) if the vessel was in transit (moving rapidly) or anchored. It was assumed an anchored vessel was fishing, while a vessel in transit (unless trolling gear deployed) was not fishing. To further document aerial survey observations, digital photographs of each observed vessel were archived and verified.

Analysis

Because the aerial survey was designed to monitor overall vessel use and activity without considering fishery estimates, sampling was not optimized to correspond with periods of peak charter use. Thus, the number of charter boats observed fishing within park waters was very low (10 boats). All strata were combined to facilitate statistical expansion by increasing sample size.

Calculation of halibut harvest and catch was possible because of a linear relationship observed during the creel survey between the number of boats fishing and number of halibut caught or harvested (equation 2.1). Separate linear regressions were observed for catch and harvest. This relationship is discussed further in the results section. Equations 2.1-2.4 were used to estimate the total harvest and catch of halibut (\hat{h}_{reg}) for charter vessels fishing in park waters.

$$\hat{h}_{reg} = b_1(K) - b_0 \quad (2.1)$$

where:

b_1 = slope of the regression line,

b_0 = intercept of regression line, and

K = number of vessels.

The variance for each point estimate $S^2(\hat{h}_{reg})$ is described in (2.2) (Neter et al. 1996).

$$S^2(\hat{h}_{reg}) = MSE \left(\frac{1}{d_h} + \frac{(k_i - \bar{k})^2}{\sum (k_i - \bar{k})^2} \right) \quad (2.2)$$

where:

k_i = i^{th} observation of the independent variable, and

MSE = mean square error for the regression in equation 2.3.

A final harvest or catch estimate (\hat{H}_{est}) was calculated by expanding the mean harvest for all point estimates (\hat{h}_{reg}) calculated in 2.1 to the sampling frame (2.3).

$$\hat{H}_{est} = D_h(\hat{h}_{reg}) \quad (2.3)$$

The variance for the final estimate of halibut harvest and catch is described in 2.4.

$$\hat{V}ar(\hat{H}_{final}) = D_h^2(1 - f_{1h}) \frac{S^2}{d_h} + \sum MSE \left(\frac{1}{d_h} + \frac{(k_i - \bar{k})^2}{\sum (k_i - \bar{k})^2} \right) \quad (2.4)$$

Telephone and mail survey methods

Offsite methods were used to estimate halibut harvest and catch that occurred within Glacier Bay proper. The offsite methods were a telephone survey for private boaters using GBNP permits to enter Glacier Bay proper. In both surveys, vessel permit requirements within the bay proper presented a known respondent list for all boats legally fishing within the bay proper.

Telephone survey

The sampling frame for the telephone survey was June 12-August 31, 2003, and included all anglers using a local permit to enter Glacier Bay proper two or more times during the sampling period. Local permit holders were sampled upon their initial entry into Glacier Bay proper by mail survey, whereas the telephone survey estimated catch and harvest on second and later entries only.

To limit recall and telescoping bias, boaters were contacted via telephone within two weeks of their completed fishing trip. ("Recall bias" oc-

curs when anglers cannot accurately recall events due to the passage of time [Pollock et al. 1994]; “telescoping bias” occurs when anglers confuse trips.) Boaters were called up to five times in an effort to contact as many as possible. The same information as described in the creel survey was elicited from respondents.

Halibut harvest and catch (\hat{H}_{tel}) were estimated using a direct expansion method as described in 3.1.

$$\hat{H}_{tel} = N \times \bar{Y} \times P \quad (3.1)$$

where:

N = population of respondents who fished,

Y = Mean harvest or catch per boating party, and

P = the proportion of parties who fished for halibut. Also, $P = n/N$, where n is the total number of respondents indicating they had fished for halibut.

Because a census was attempted, the sample variance was assumed to be an unbiased estimate of the population variance.

Mail survey

A census was attempted on all boaters over the age of 17 who had an Alaska fishing license and entered Glacier Bay proper aboard a private boat for the first time during the general permitting season: June 1-September 15, 2003. Boaters using the general or local permitting system are required by GBNP to complete an orientation at the GBNP visitor information station (VIS) upon entering the park for the first time each season. Following the required orientation, VIS staff urged respondents to complete a questionnaire and survey.

Boaters agreeing to complete the survey were given a packet containing the following: an introductory letter that explained management reasons for conducting the survey, a contact questionnaire that was completed before their trip, a survey form to be completed while on their trip, a park map showing predefined statistical areas, and a prepaid return envelope. The contact questionnaire was used to obtain general demographic information, whether respondents possessed a valid Alaska fishing license, and provided names and addresses used for follow-up mailings. The mail questionnaire asked respondents about the number of rods and hours spent fishing at each location for a type of fishing (halibut, salmon, or bottomfish). Catch and harvest information for each type of fishing at each location was also requested. Information was recorded for each day fished within Glacier Bay proper.

In theory, all visitors who entered the park for the first time during the 2003 season would have submitted a completed contact sheet, thus providing a record of the entire first-visit-of-the-season boating population. In reality a census was not obtained because survey technicians missed potential respondents during orientation. Instead, the total number of possible respondents was obtained from park records. The contact questionnaire was used to obtain contact information and evaluate response biases between groups of differing age and gender.

In an effort to increase response rates, three follow-up reminder letters were distributed to all participants who completed a contact sheet: the first reminder letter was sent to all participants within two weeks of initial contact; the second reminder, containing another survey packet, was mailed within two weeks of the initial reminder to those who had yet to return their mail survey; and a final third reminder was mailed six weeks after the distribution of the first letter to anyone who had not returned their survey.

Results

Gustavus creel survey

Halibut harvest and catch levels based on reports by charter anglers in Gustavus were low, as indicated by only 59 (SE = 12.5) halibut harvested and 80 (SE = 13.3) halibut caught directly adjacent to Glacier Bay proper. High variability in catch and harvest across days resulted in low precision for catch (32.9%) and harvest (41.9%). Moreover, it is likely estimates are biased low due to large misreporting error discussed later in this paper.

Aerial survey

To quantify misreporting that occurred during the Gustavus creel survey using aerial methods outlined in equations 2.1-2.4, linear regressions comparing catch and harvest (dependent variable) with effort (independent variable) were modeled (Fig. 2). Normalizing both the dependent and independent variables with a square root transformation reduced heteroscedasticity in the residuals. The resulting regressions had strong relationships between the dependent and independent variables as demonstrated by an R^2 of 0.74 for harvest and 0.70 for catch.

Estimates of halibut harvest and catch using aerial survey methods were 123% and 333% higher than creel survey estimates, respectively. The estimated halibut harvest and catch using aerial survey methods was 99 (SE = 30.7) and 197 (SE = 64.5) fish, respectively. Based on these results, charter anglers operating from the Gustavus dock accounted for 12% of the total catch and harvest in Glacier Bay (Table 1). Due to the small sample size in the aerial survey, the relative precision for estimates was low: 65% for catch and 61% for harvest estimates.

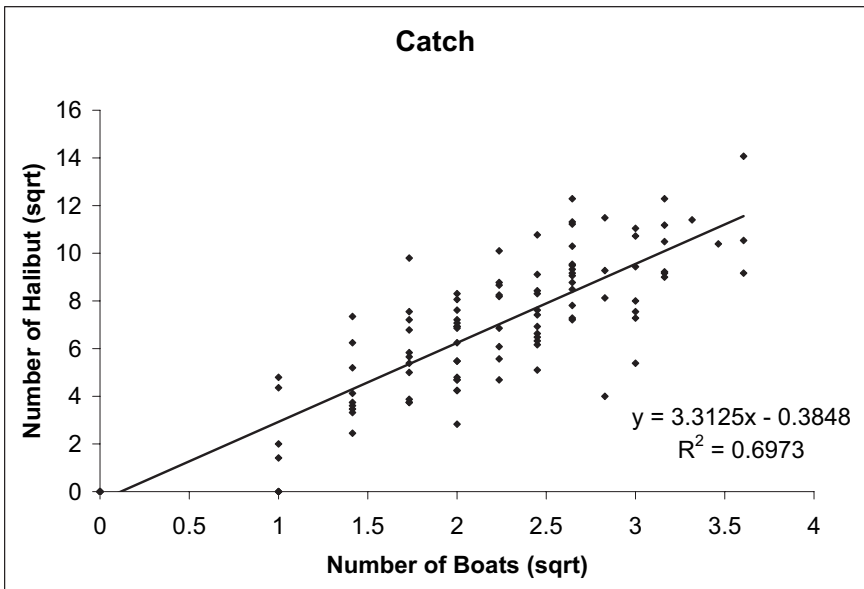
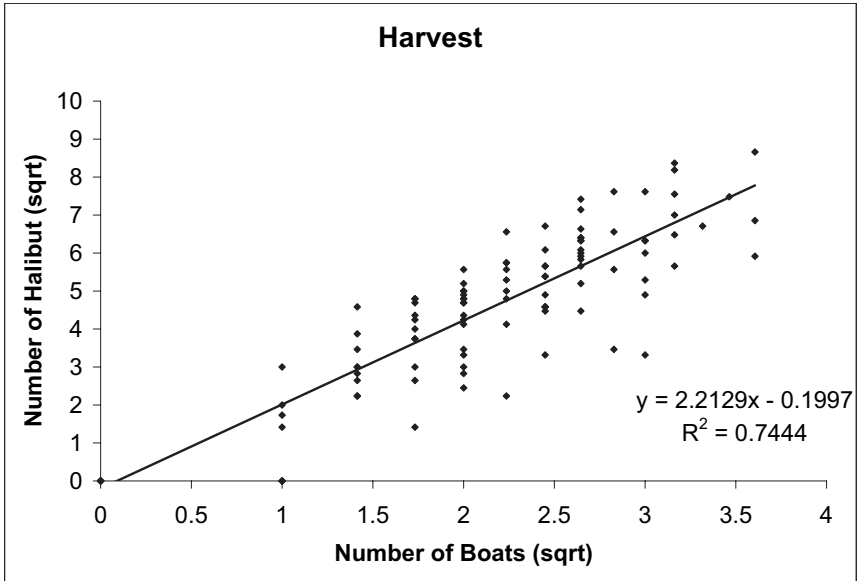


Figure 2. Linear relationships between halibut catch/harvest (individuals) and bottomfishing effort (rod hours) for charter sport boats originating from the Gustavus sampling site. (sqrt = square root.)

Telephone survey

During the survey period, a total of 115 respondent phone numbers were called, of which 5 were no longer in service and 86 were contacted (78.1% response rate observed). Of the 86 respondents contacted, 79.1% indicated they fished. Assuming this percentage reflects the entire population, then 79.1% of the local permit holders on their second or later visit had someone in their party fish. Thus, the total number of parties that could have fished during the survey period was 91 (115×0.791).

Local permitted anglers who entered Glacier Bay proper on their second or later trip accounted for 31% of both the total halibut catch and harvest (Table 1). An estimated 496 (SE = 6.54) halibut were caught and 261 (SE = 3.4) harvested in park waters. Most of the halibut catch and harvest occurred within 1 mile of Bartlett Cove. The near census resulted in very high precision for catch (2.6%) and harvest estimates (2.5%). The near census also insured the estimates were representative of the population and reduced the potential for a biased estimate. It is unlikely that recall bias was an issue for this survey because call-back periods were short (<2 weeks).

Mail survey

A total of 156 useable addresses were obtained from a population of 729 boaters who entered Glacier Bay on their first visit of the 2003 season. A response rate of 62.8% was observed, of which 46.2% indicated they used fishing gear that targeted halibut. Since only 21% (156/729) of potential respondents were contacted, the chances for biased estimates may be high.

Data from the questionnaire completed during orientation provided an opportunity to evaluate possible differences between respondents and non-respondents using chi square and *t*-tests. Such tests assessing possible non-response bias were focused on two categories of characteristics: (1) visitor characteristics, included gender, age, residence, and whether the visitor was the permit holder for the group; (2) group characteristics, included the number of visitors in the party, the type of visitor group (i.e., family, friends, etc.), whether the group included members under age 18, and how many people in the group had Alaska fishing licenses. Statistically significant differences in response rates were found for visitor age (characteristic 1). Respondents who returned the mail-back questionnaire averaged 54 years, whereas those who returned only the contact sheet averaged 50 years, $t(158) = -2.40$, $P = 0.02$. Response differences by age are very common in this type of survey (Osterhoudt et al. 2004) and additional analysis suggested the effects of respondents' age on the variable measured in this mail survey were not large enough to alter representativeness of the sample in important ways; however, it is impossible to completely rule out undetected examples of non-response bias.

Table 1. Estimated halibut harvest and catch by survey type.

	Catch			Harvest		
	Estimate	SE	Rel. Prec. ^a	Estimate	SE	Rel. Prec.
Mail	904	6.1	1.3%	485	2.3	0.9%
Telephone	496	6.5	2.6%	261	3.4	2.5%
Creel	80	12.5	41.5%	59	13.3	32.6%
Aerial	197	64.5	64.1%	99	30.7	60.8%
Total ^b	1,597	65.1 ^c	8.0%	845	31.0	7.2%

^aRel. Prec. refers to the relative precision statistic: $SE \times 1.96 / \text{estimate} \times 100$.

^bSum of mail, telephone, and aerial survey estimates.

^cStandard error (SE) is calculated as the sum of the $\sqrt{V\hat{a}r}$ for each survey. Survey populations are independent from each other; thus the total SE is the square root of the sum of each survey variance ($SE_{\text{total}} = \sqrt{V\hat{a}r(\text{telephone}) + V\hat{a}r(\text{mail}) + V\hat{a}r(\text{aerial})}$). The creel survey variance is excluded from the total SE.

Local and general permitted anglers who entered Glacier Bay proper for their first time accounted for 57% of both the total halibut catch and harvest (Table 1). An estimated 904 (SE = 6.1) halibut were caught, of which 485 (SE = 2.3) were harvested in park waters.

Discussion

The results of the four survey methods provided estimates of fishing harvest and catch for halibut within GBNP waters. The creel survey accounted for the smallest catch and harvest and was biased low when compared with aerial survey estimates. The mail and telephone surveys accounted for the majority of the catch and harvest. The aerial and creel surveys had the lowest precision, while telephone and mail surveys had the highest relative precision.

The large reporting error in the Gustavus creel survey, as demonstrated by the aerial survey, resulted in a gross underestimate of halibut harvest and catch. These high misreporting levels may have been due to some charter anglers not knowing (or not paying attention) to the location of park boundaries outside Glacier Bay proper, non-permitted charter vessels operating within the park, guides avoiding the need to file use reports or logbooks at the end of the season as required by GBNP, or apprehension about providing creel census data to the park due to privacy concerns. The reasons behind misreporting were not studied in this report. Therefore, the above-mentioned reasons are conjecture, but are provided to demonstrate the impact external survey factors can have on a survey program. Assessment of user attitudes toward a survey program is especially important in a data limited situation. Without the aerial survey,

park managers would not have been able to quantify reporting bias in the creel survey and adjust estimates accordingly.

Aerial surveys generally are not used to estimate catch (Pollock et al. 1994) because it is difficult to determine a boat's origin and if the boaters were actively fishing. This problem was circumvented with the use of high-resolution digital photography. The identity of individual sportfishing boats could be accurately determined and matched with creel survey data. The remote nature of the GBNP sportfishery facilitated the meshing of creel surveys with the aerial survey because few high-use access points exist. Survey situations that have many access points and/or transient boaters from communities outside the sampling universe may have difficulties with this method because the catch or harvest statistic cannot be assessed using creel survey methods. Furthermore, the high correlation observed between catch and effort allowed development of a regression model for halibut fishing that could be used to estimate catch based upon observed effort. More variable fisheries may not have a strong enough relationship between catch (or harvest) and effort to establish a reasonably accurate model.

Despite the economic concerns associated with large complex surveys, it is particularly important in data limited situations to assess sources of bias. Brown (1991) best summed up the economics of survey design with the statement: "The problem is that the cheap biased data are not cheap. They are barely affordable." This was particularly relevant to this survey, where high misreporting was observed in the creel survey, a small portion of the population was captured in the mail survey (which may result in a biased estimate), and the telephone survey was a relative success. Despite the higher costs potentially accrued from using four different survey methods, all surveys were needed to assess bias and provide baseline data to inform future survey designs. In particular, large costs associated with aerial and creel surveys were offset by the information gained about creel survey bias.

Conclusion

Managers should view offsite survey results with caution due to recall and non-response bias. In this study the offsite telephone survey was the most accurate out of the three survey methods (creel, mail, and telephone surveys). For larger scale fisheries with multiple fishing sites, telephone surveys would be very difficult to implement. However, in specific areas (i.e., a bay or special use area), telephone surveys are useful for estimating catch, harvest, and effort in a sportfishery. Moreover, telephone surveys could be used to validate other survey methodology. For instance, a sample of respondents fishing in a known area, that was surveyed using mail-out methods, could be surveyed using a telephone survey (i.e., mail complemented with a telephone survey). This may expose problems in

survey design such as fishing occurring on statistical or political boundaries, misreporting, and recall bias.

The data limited situation encountered in this study was characterized by a lack of baseline data on use levels, the distribution of use across ports and on the fishery grounds, and misreporting problems. Without the benefit of using an aerial survey, it would have been very difficult to determine reporting accuracy of the creel survey at the Gustavus dock. This survey did not evaluate the accuracy of mail and survey responses. Future studies need to assess the accuracy of the mail and telephone surveys and use fishery independent methods complemented with a creel survey at Gustavus to estimate the amount of halibut catch and harvest occurring in park waters.

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