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Introducing a New Trawl Survey for U.S. West Coast Slope Grouudfish

by

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Introduction

In 1998, the Fishery Resource Analysis & Monitoring Division of the NMFS Northwest Fisheries Science Center (NWFSC) conducted a new bottom trawl survey of the commercial groundfish resources of the slope zone (100 to 700 fathoms; 183 to 1,280 m) off the continental U.S. West Coast (Washington, Oregon, and California). This was motivated by the determination in the mid-90's that stock assessments for these slope groundfish species did not have sufficient data to provide precise results. The critical need for greater precision in stock assessments was also highlighted in the 1990's as five groundfish species declined into a depleted state.

One of the objectives of the new survey was to complement and extend two pre-existing resource surveys that have been conducted on U.S. West Coast groundfish by the NMFS Alaska Fisheries Science Center {AFSC). Before 1998 these two surveys were the principal sources for fishery-independent data on the status and distribution of the commercial groundfish resources of the slope zone.

> The AFSC's West Coast shelf survey has been conducted in the summer every three years since 1977 using two chartered vessels, covering the continental shelf habitat from 30 to 200 fathoms (55 to 366 m) thus overlapping the inshore portion of the slope zone. This survey was designed primarily to assess various rockfish species (*Sebastes* spp.) and the trawl's footrope is equipped with roller bobbins to allow fishing in rougher habitat.
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> The AFSC's annual slope survey began in 1984 and has been conducted in the autumn nearly every year since. The AFSC slope survey covers the continental slope habitat from

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100 to 700 fathoms (183 to 1,280 m) and has employed the NOAA research vessel 'Miller Freeman" every year except 1984 and 1989. This survey uses the same net as that used for the shelf survey, but with a rubber disk footrope to improve bottom contact. Prior to 1997, the annual latitudinal extent was limited (Figure 1) because of limited vessel time and the unfamiliarity with the grounds being covered in the early years. In 1993, concerns were raised regarding the performance of the trawl gear. Gear studies conducted in 1994 (Lauth *et* al., 1998) resulted in modifications to the rigging and towing protocols when the survey resumed in 1995. When coastwide coverage was instituted in 1997 and 1999 (Lauth, 2000) it came at the price of reduced sampling density.

The West Coast fishing industry has been a strong proponent of cooperative survey work. Their interest in a cooperative survey, the limited budget available to expand West Coast surveys, and the new cooperative research provisions of the Magnuson-Stevens Sustainable Fisheries Act provided an opportunity to develop a new survey methodology and vessel compensation strategy to take advantage of the skills of skippers familiarwith the unique challenges of fishing the deep waters off the West Coast.

The vessel compensation package for the new survey incorporates three components. First, half of the vessel's compensation comes in the form of a cash payment on successful completion of the contracted survey. Second, during actual survey operations each vessel's crew retains and preserves any commercially valuable fish caught during sampling hauls. The 5-day legs of the survey are designed to allow the vessel to keep these fish in good condition so they can be sold to provide a portion of the vessel's total compensation. Finally, the remainder of the vessel's compensation comes in the form of an exempted fishing permit that grants the vessel additional fishing opportunities after the survey's end that may be used to catch a specified amount of fish worth the balance of their payment for the survey. The amount of this payment catch is adjusted by the amount received for sales of survey-caught fish so that the vessel's total compensation is fixed, providing no incentive to increase catches during survey operations. The total amount of fish used for survey compensation is less than 1% of the total allowable catch (TAC) for each of the survey's target species, and is deducted from the TAC for the entire fishery. Thus, all vessels participating in the slope fishery help pay for the survey. It was feasible to develop such an approach for the West Coast groundfish fishery because vessels licensed for this fishery have a monthly cap on their allowable landed catch for each of several species. These limits were implemented in order to reduce the aggregate rate of catch by the fleet, thus allowing a year-round fishing, processing, and marketing opportunity. The exempted fishing permit for the chartered vessels allows them to land fish in excess of their normal monthly limit, up to the amount specified by the permit. Thus, those vessels that possess licenses for the West Coast groundfish fishery comprise the pool of vessels that could realistically bid for conducting this survey.

Working with a new class of vessels presented some challenges when designing the survey. These primarily stemmed from the small size (~ 23 m) of the trawlers available in this fleet relative to the "Miller Freeman" (- 66 m) and the larger trawlers (-'35 m) chartered for the AFSC triennial shelf survey, which ordinarily fish in Alaskan waters. Coastal groundfish trawlers typically are not sufficiently powerful to tow the standard sampling trawl used by both the "Miller Freeman" and the triennial survey vessels so it was necessary to designate a new standard sampling gear for these smaller vessels, and this in turn created a difference in absolute catch rates in comparison to the historical trawl surveys on the slope. Further, most coastal vessels do not have accommodations for as many scientific personnel as typical Alaska trawlers so it was necessary to adapt the sampling objectives and methodology to the constraints imposed by having smaller field parties. Finally, the smaller vessels are more weather-limited, so the timing of the survey is restricted to the summer period. Still; if these difficulties could be overcome the advantages of employing these vessels and exploiting the skills of their captains seemed to outweigh the disadvantages.

The new survey described here was designed to increase the sampling density of survey effort within the slope zone and to obtain this information in the same season as the AFSC shelf survey. Using chartered U.S. West Coast fishing vessels, exploratory work was conducted in 1997, followed by a pilot survey in 1998, then full-scale surveys in 1999 and 2000.

Methodology development

Preliminary experiments were carried out in the summer of 1997 (West ***et al.,*** unpubl.) to assess whether or not this approach was sound, and if so to develop methodologies appropriate to both the needs of the survey and the capabilities of typical local vessels. Using trawl instrumentation, two types of trawls commonly used in the West Coast commercial groundfish fisheries were tested across a representative range of vessel sizes, fishing depths, and other operational factors in order to identify which gear offered the most stable physical and fishing performance and would thus be more suitable for use as a standard sampling trawl. In addition to facilitating a choice for an optimal sampling gear, this work also demonstrated the range of variation in gear performance likely to be seen under typical survey conditions and verified the need to observe and control sampling trawl performance by means of trawl instrumentation and other aids.

These experiments also provided insight into the challenges associated with using small scientific parties to acquire and record the required biological data from the catches. This preliminary work in 1997 and the first survey in 1998 were conducted with two scientists on board, plus the vessel's skipper and crew of two. From this experience it was possible to set realistic expectations of what kinds of biological parameters could be recorded and at what level of detail, to spot potential bottlenecks in the catch analysis process, and to identify promising technological and methodological solutions to such bottlenecks. In 1999 and 2000, the scientific staff was increased to three per vessel in order to better accomplish the sampling.

The experiments demonstrated that acceptable results could be obtained at acceptable levels of scientific rigor, and showed how this could be done. However, they also showed that survey operations under these conditions do suffer some inherent limitations, especially in the realms of collecting and storing large volumes of tissue samples and other specimens, conducting other detailed biological examinations or oceanographic sampling, providing quarters for scientific staff, and carrying out specialized, technically demanding operations.

Multi-vessel considerations

Multiple vessels must be used to conduct this survey in order to obtain a sufficient number of samples over the large geographic area in a sufficiently short period of time. The statistical design of the survey and its analysis must take into account the between-vessel component of variance so that the benefits of increased sample number can be realized. Standardization of methodology and gear mensuration can greatly reduce the magnitude-of between-vessel variance and allow the use of multiple vessels to conduct extensive surveys. Such an approach is successfully used to conduct multi-vessel surveys in the Bering Sea (Goddard and Walters, 2000), Gulf of Alaska (Stark, 1997), U.S. West Coast (Wilkins et *al.*, 1998) and Gulf of St. Lawrence (Fréchet, 1997). However, subtle differences in vessel noise or other poorly-understood factors can cause differences in vessels' catching efficiency, which leaves some residual difference between vessels in these multiple vessel surveys (Sissenwine and Bowman, 1978; Byrne and Fogarty, 1985) and probably introduces some inter-annual differences in the results of surveys conducted with the same vessel.

A traditional approach to dealing with vessel differences is to conduct calibration studies, Such studies are especially important when a new vessel is introduced to a single vessel survey. Using identical gear on similar vessels, comparative fishing experiments have shown that inter-vessel catch rates can vary by as much as a factor of two for some species (Sissenwine & Bowman, 1978; Byrne & Fogarty, 1985). The power of calibration studies is very low due to high inherent haul-to-haul variability (Wilderbuer et al., 1998; McAllister, 1995), so a survey design that requires frequent calibration studies would be prohibitively expensive.

An alternative approach to dealing with between-vessel catching efficiency is to establish a design that subsumes these differences into the overall survey variance without allowing the differences to introduce bias in the ultimate goal: a time series of relative abundance data. Such an approach is used for the U.S. West Coast triennial shelf trawl survey which uses two closely matched vessels to conduct essentially replicate surveys by alternating track lines (Wilkins *et al.,* 1998). Because of the strong emphasis on towing standardization and gear mensuration the results from the two vessels are pooled without any explicit adjustment for possible differences in catching efficiency. Any residual difference between vessels simply contributes to the overall survey variance.

If there is moderate to large variability in catching efficiency between vessels, then the use of only one or two randomly selected vessels will introduce an inter-annual vessel signal that will confound attempts to track the relative abundance of the survey's target species. As shown in McAllister's analysis (1995), as the number of participating vessels increases the combined results dilute the contribution of each individual vessel to provide a less biased index of fish abundance. In the Bering Sea case evaluated by McAllister, the results suggest that the use of 6 replicate vessels would provide the best tradeoff between reduction in bias and introduction of variance. Preliminary results from a similar modeling exercise using data from our own 1998 survey showed the same patterns '(Figure 2): 1) that year-to-year overall variance in survey biomass estimates was reduced as the number of participating vessels increased; 2) that the incremental gains in precision with additional vessels were greatest when going from one vessel to two, still strong but not as strong when going from two to three, three to four, etc., with little benefit to be realized beyond six or so vessels; and 3) that vessel-vessel variability was at levels comparable to those found by McAllister.

When multiple vessels are used in a survey, it is likely that some vessels will be used repeatedly over time. To some degree, this is contrary to the statistical design of the analysis, which is based upon each year's selection of vessels to represent a random collection from a large universe of potential vessels. However, other factors (weather, crew, vessel equipment, etc.) can add to the variability between vessels even when the vessels remain the same. As a time series of survey results accumulates, subsequent statistical analyses will be able to use general linear modeling to explore the degree of variability between vessels and the degree to which the vessel effect for repeat vessels is stable over time.

Survey design

The NWFSG slope survey's design is primarily driven by the need to produce an accurate index of year-to-year trends in slope species abundance and distribution so most sampling design elements are drawn from conventional area-swept bottom trawl survey methodology. However, the multi-vessel aspect of the survey design provides both a need and an opportunity to introduce elements from the methodology of comparative fishing experiments.

As is customary in most bottom trawl surveys there is strong emphasis on strict adherence to standardized gear and rigging specifications, on compliance with standardized operational protocols while conducting the sampling tows, and on rigorous catch sampling and analytical procedures. Efforts are made to measure and record those aspects of each sampling operation and its surrounding circumstances that cannot be controlled through standardization.

The trawls, rigging, and accessories are of a type commonly used in slope commercial fisheries, scaled to fit the class of vessels chartered for this survey and which range from 400 to 600 horsepower. The standard trawls, are of the "Aberdeen'" four-panel type with a headrope length of 85 feet (25.9 m) and a footrope length of 104 feet (31.7 m). Small-mesh (50 mm stretched measure or less) codend liners are installed in order to retain juvenile fish and other small organisms. Each trawl is fitted with a footrope constructed of S-inch (200 mm) rubber discs threaded over 13-mm alloy long-link chain. Each trawl is rigged with 15-fathom (27.4 m) double bridles leading to a 15-fathom (27.4 m) single sweep attached to 5' x 7' (3.5 sq m) steel Vee-doors, the lower bridle and single section on each side covered with rubber discs.

All tows must be conducted entirely between sunrise and sunset as determined by latitude-specific almanac data. The target towing speed for all depths is 2.2 knots, although some flexibility is granted to allow for adverse weather, currents, or other circumstances.

Each of the four vessels used for each year's slope survey is assigned its own set of sampling stations such that it conducts its own independent survey of the full north-south and onshore-offshore extent of the survey area. This approach reduces the risk of confounding vessel effects with large-scale distribution patterns, and provides an opportunity to evaluate systematic between-vessel differences.

The four vessels operate in pairs, with two vessels conducting their cruises sometime between late June and early August, and the second pair starting in late August and concluding in late September. Ideally all four vessels would operate simultaneously but staffing, logistical, and other concerns preclude this at this time. This time period was chosen for several reasons including: 1) it is believed that most of the survey's target species do not undergo any substantial migratory or other movements during this period, 2) this season offers the highest likelihood of weather conducive to survey operations, and 3) this is the time period of the historical trawl survey on the continental shelf.

Sampling station locations are selected by a combination of systematic and stratified-random approaches. All stations are located along east-west transects, with 80 such transects arranged 10 minutes of latitude (10 nautical miles) apart from Cape Flattery, Washington, (48" 20' N.) to near Point Conception, California (35° N.). The inshore and offshore boundaries of each transect are the 100-fm (183-m) and 700-fm (1,280 m) isobaths. Each vessel is assigned its own set of 20 of these transects, each transect 40' from the ones above and below it, and the four sets interleaved such that at the survey's conclusion each vessel will have conducted its own coastwide mini-survey and all 80 transects will have been occupied (Figure 3).

Five sampling stations spanning the full depth range are assigned along each transect according to a stratified-random sampling scheme. From what is understood about the biology and life history of the survey's target species @over sole, shortspine and longspine thornyheads, and sablefish, collectively termed the DTS species complex) it was felt that two significant depth strata within the 100-700 fm slope zone could be designated: a shallow zone from 100 to 300 fathoms and a deep zone from 300 to 700 fathoms. Each stratum is divided into five depth bins, each bin spanning an equal depth interval within its stratum. This yields five 40-fm bins in the shallow stratum and five 80-fm bins in the deep stratum for a total of ten depth bins along each transect. Because survey design constraints require that each vessel spend no more than one day at each transect, and no more than five tows can be accomplished in one day, five stations are selected from among the ten possible depth bi-ns on that transect. Three bins are randomly selected without replacement in the stratum featuring the greatest East-West extent along its portion of the transect, and two bins are similarly selected from the "narrower" stratum. In this way sampling intensity is linked to the relative area1 extent of each stratum.

Because of the complex bottom topography and other impediments to trawling found over much of the survey area, the exact location of each sampling tow within its bin is left to the vessel captain's discretion. Using charts, the vessel's echosounder, and his own skill and experience, at each station the captain searches for a suitable tow location. The selection criteria are that it must be possible to accomplish the entire tow within the upper and lower depth boundaries of the bin, and within a zone ten nautical miles wide from north to south centered along the assigned transect (Figure 4). At each station two hours are allocated for searching for a tow location meeting these criteria; if none can be found after two hours the station will be abandoned as "untrawlable" and the vessel will proceed to its next assigned station.,

Nominal tow duration for every tow is 15 minutes starting from the moment that the trawl reaches the bottom, assumes its normal fishing configuration, and starts fishing, until the moment

15 minutes later when haulback operations begin. This tow duration was selected in order to keep catch sizes small enough that they could be completely sorted and analyzed without splitting or otherwise subsampling the catch. A study by Goddard (1997) involving a survey situation similar to ours concluded that subsampling can be comparable to gear malfunctions or a reasonably strong vessel effect as a source of error in characterizing catch species- and size-composition. In comparisons of short versus long sampling tows, Goddard's and other studies (Godø *et al.,* 1990, and Walsh, 1991) have found that tow duration affects neither the quantity caught per unit of effort nor the species- or size-composition of the catch. An additional practical benefit of shorter tow durations is that they make it easier to find and successfully accomplish sampling tows over challenging substrates, thus increasing the number of tows that can be made and improving the survey's ability to sample a wider range of the habitats found in the survey area.

When catch-per-unit-of-effort (CPUE) is the critical measured variable, as it is in this and all area-swept trawl surveys, it is essential that sampling (fishing) effort be controlled as precisely as possible and accurately measured whenever it cannot be controlled. This becomes even more important when tow durations are short, as they are here, since a few minutes' error in actual vs. nominal tow duration or a few hundred meters' error in distance fished can have relatively large impacts on CPUE-derived abundance estimates. In response to these concerns, the NWFSC slope survey design features extensive acquisition, and logging of data on numerous vessel and gear performance parameters during every sampling tow. Wherever feasible all data are logged automatically at high rates on a portable computer, with backup data records made on paper by the scientific party.

Data logging is initiated once a tow location has been found and trawl deployment is under way. In order to take advantage of its high accuracy and repeatability, all time and position information is obtained from a differential Global Positioning System (DGPS) receiver. A Simrad IT1 trawl instrumentation system linked to the DGPS unit is used to continuously report information on both trawl performance and trawl position in latitude and longitude via an acoustic link to the vessel. Data from these two input sources are directly output to a portable computer running data-logging software, which logs the times, positions, and other parameters several times per minute. In addition to this automated logging process, the Field Party Chief (FPC) can toggle special logging events in response to important milestones during the tow. These include the moment the vessel starts paying out the trawl, the moment the trawl doors are first lowered into the water, the moment at which the doors are fully deployed and the trawl winches are stopped, the moment at which the trawl first contacts the bottom, the beginning of. the sampling tow when the trawl has assumed its fishing configuration and the vessel is at towing speed, the nominal end of the tow fifteen minutes later when gear recovery is initiated, the moment at which the trawl lifts away from the bottom, and finally the moment at which the trawl doors are recovered.

Many of these values are also recorded manually by the FPC, although much less frequently, along with various other parameters concerning the tow and its circumstances. These include observations of the water depth below the vessel as recorded by the ship's echosounder, the towing speed, the scope (the deployed length of the towing warps), and characterizations of weather, current, and other relevant environmental factors.

In addition to the time and position data, the ITI system measures and reports several important trawl performance parameters in real time. These are automatically logged as described above, and periodically recorded manually by the FPC as well. These parameters include the trawl's vertical opening at thecenter of the heaclrope, the distance (if any) between the footrope and the bottom, the trawl's horizontal spread from wingend to wingend, the trawl's depth below the surface, and the water temperature at the trawl. In addition, mechanical bottom contact sensors (BCSs) are deployed to obtain independent confirmation of tow duration and bottom tending, and to serve as backup sources for these data in case of IT1 malfunctions. These BCSs are self-logging tilt sensors hanging below the footrope so that they are vertical when the gear is off bottom and near-horizontal when the trawl touches down, and they are downloaded following trawl recovery for display and logging on the computer.

Besides effort, the other major components of CPUE are the quantity and composition of the catch. In addition, there is other valuable biological information to be obtained from analyzing the catch or specimens drawn from the catch. The objectives and techniques used for catch work-up are similar to those generally employed for groundfish trawl surveys, with some adaptations made on the basis of our data needs and working circumstances. 'Likewise, some of our procedures have evolved as we have gained insight and experience in the two years the survey has been conducted.

The first step in our catch analysis is to sort the entire catch into species or other appropriate taxa, then determine the weight and number of each species or other category. In the first year, when most field parties comprised only two biologists, only the DTS species were consistently sorted to species although other species were occasionally sorted out as time and workload allowed. In 1999 the size of each field party was increased to three biologists, making it possible to sort all finfish and crabs to species. Other invertebrates are sorted to species whenever time and expertise permit.

A representative sample of the four DTS species is measured, as well as a limited number of other species when they are encountered. Dover sole and sablefish are sorted by sex before being measured but not the two thornyhead species. Otoliths are collected from a subsample of each of the DTS species, and indices of reproductive status are recorded for a subsample of sablefish.

Preliminary results from the two years are encouraging. In 1998, successful tows were made at 319 out of 400 possible stations, or about 80%. Twenty-four stations were not sampled due to untrawlable bottom or the presence of communications cables or submarine lanes, and tows were not attempted at 56 stations due to bad weather, lack of time to conclude a tow during daylight hours, or other logistical constraints. In 1999, successful tows were made at 344 out of 400 possible stations, or over 85%. Untrawlable bottom or other physical features made it impossible to occupy 12 stations, while weather, daylight considerations, and logistical constraints precluded attempts at 44 stations.

Gear performance was quite consistent and satisfactory from year to year and vessel to vessel. In general the trawls exhibited consistent, stable ground contact. There were a few instances, typically early in a cruise, when the trawls "dug in" as demonstrated by catches of large quantities of mud, but these were quickly set aright by making minor adjustments to the trawl rigging, The operating dimensions of the trawls were quite consistent under all conditions including across the different vessels, at all fishing depths, and in both years.

The trawl instrumentation and effort logs yielded an important finding (West et al., 1999). The observations made in 1998 raised concerns that the trawls might be continuing to fish during the retrieval period, after the end of the sampling period but before coming off bottom during haulback. Using the logged times and positions at critical moments during and following each sampling tow, a geometric analysis was used to estimate the distance over the bottom that was covered by the gear during the retrieval period, and the speed at which the trawl moved over the bottom. This analysis found that the distances swept were substantial and systematically increased with the depth of the tow, in the worst cases exceeding the distances covered during the 15-minute nominal sampling period. Likewise, the trawl's speed of advance over the bottom during this period approached or even exceeded the 2.2-kn towing speed specified by the sampling protocols, and varied systematically among the participating vessels. Neglect of such effects could increase the impact of depth-related bias and inter-vessel variability on survey results.

During the 1999 NWFSC slope survey improvements in our data-logging software made it possible to directly log the trawl's positions as reported by the ITI, instead of back-calculating them geometrically as was done for the 1998 data reported by West et *al.* (1'999). Analysis of these data revealed similar depth-dependent and vessel-dependent effects on the distance and speed of advance of the trawl during the haulback period (West and Wallace, 2000). Comparisons of the position data obtained with the trawl instruments against position estimates made using the prior year's geometric analysis showed very good agreement and validated the earlier technique.

Conclusions

Preliminary indications suggest that this approach to multi-vessel surveys can be effective. Sampling effort can be successfully standardized to help reduce bias and variability, and where standardization reaches its effective limits, variations in the actual area sampled can be directly measured. Residual differences in vessel-related catching efficiency appear to be within a range that is amenable to existing analytical procedures and should not have an excessively negative impact on our ability to produce an accurate index of year-to-year trends in abundance and distribution. Sampling techniques were developed that make it possible for small scientific parties to acquire and record the data needed for stock assessments and other analyses. A preliminary review of between-vessel effects and comparison to the AFSC's shelf and slope surveys is underway.

References

Byrne, C.J., T.R. Azarovitz, and M.P. Sissenwine. 1981. Factors affecting variability of research vessel trawl surveys. In W.G. Doubleday and D. Rivard (Eds.), Bottom trawl surveys/Relevés au chalut de fond. Can. Spec. Publ. Fish. Aquat. Sci./Publ. spéc. can. sci. halieut. aquat. 58.

Byrne, C.J., and M.J. Fogarty. 1985. Comparison of the fishing power of two fisheries research vessels. Northwest Atlantic Fisheries Organization Scientific Council Meeting-Sept. 1985. NAFO SCR Doc. 85/90. 14 p.

Fréchet, A. 1997. The use of multiple commercial boats to conduct a stratified-random survey for groundfish in the Gulf of St. Lawrence. Intern. Coun. Explor. Sea. ICES C.M. 1997/W:01.

Goddard, P.D. 1997. The effects of tow duration and subsampling on CPUE, species composition and length distributions of bottom trawl survey catches. M.S. Thesis, University of Washington, Seattle, WA, 119 pp.

Goddard, P.D., and G. Walters. 2000.1997 bottom trawl survey of the eastern Bering Sea continental shelf. AFSC Processed Report 2000-02, NMFS, AFSC, 7600 Sand Point Way NE, Seattle, WA.

Godø, O.R., M. Pennington, and J.H. Vølstad. 1990. Effect of tow duration on length composition of trawl catches. Fisheries Research 9: 165-179.

Kappenman, R.F. 1992. Estimation of the fishing power correction factor. AFSC Processed Report, NMFS, AFSC, 7600 Sand Point Way NE, Seattle, WA.

Lauth, R.R. 1999. The 1997 Pacific West Coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-98,284 p.

Lauth, R.R. 2000. The 1999 Pacific West Coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-115,287 p.

Lauth, R.R., S.E. Syrjala, and S.W. McEntire. 1998. Effects of gear modifications on the trawl performance and catching efficiency of the West Coast upper continental slope groundfish survey trawl. Marine Fisheries Review 60(1): l-26.

McAllister, M. 1995. Using decision analysis to choose a design for surveying fisheries resources. Ph.D. dissertation, University of Washington, Seattle, WA.

Sissenwine, M.P. and E.W. Bowman. 1978. An analysis of some factors affecting the catchability of fish by bottom trawls. ICNAF Res. Bull. 13: 81-87.

Stark, J. 1997. Report to industry: Fishing log for the 1996 bottom trawl survey of the Gulf of Alaska. AFSC Processed Report 97-05, NMFS, AFSC, 7600 Sand Point Way NE, Seattle, WA.

Walsh, S.J. 1991. Effect of tow duration on catch per unit effort and length composition of bottom trawl surveys: a preliminary analysis. Presented to the ICES Working Group on Fishing Technology and Fish Behaviour. 17 pp.

West, C.W., D.R. Gunderson, and R.D. Methot. Unpublished Ms. Evaluation of west coast slope survey methodology.

West, C.W. and J.R. Wallace. 2000. Measurements of distance fished during the trawl retrieval period. ICES CM 2000/K:37. 14 pp.

West, C.W., J.R. Wallace, and T.A. Turk. 1999. Modeling trawl performance during the retrieval period. Presented to the ICES Working Group on Fishing Technology and Fish Behaviour, St. John's, Newfoundland.

Wilderbuer, T.K., R.F. Kappenman, and D.R. Gunderson. 1998. Analysis of fishing power correction factor estimates form a trawl comparison experiment. North Am. Jour. Fish. Man. 18:11-18.

Wilkins, M.E., M. Zimmermann, and K.L. Weinberg. 1998. The 1995 Pacific West Coast bottom trawl survey ofgroundfish resources: Estimates of distribution, abundance, and length and age composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-89,138 p. plus Appendices.

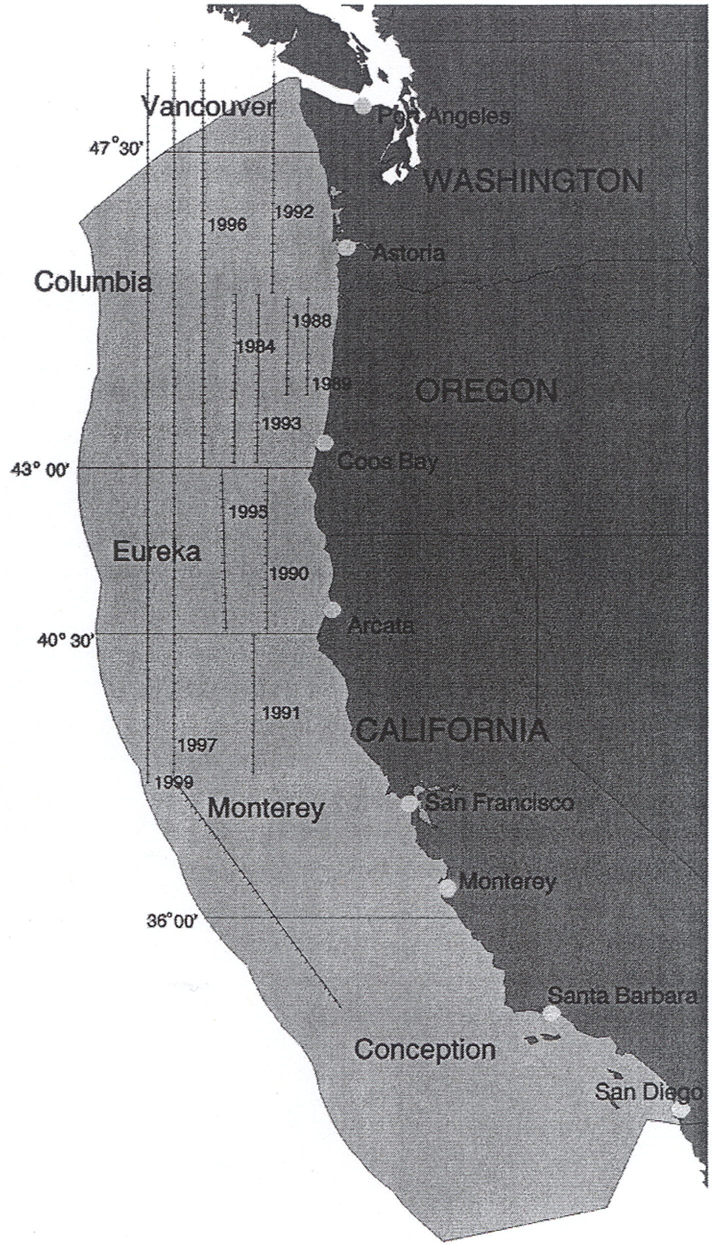

Figure 1. Annual latitudinal coverage in the AFSC slope survey. North-south positions are depicted accurately, while east-west locations are exaggerated for illustrative purposes. The shaded area offshore depicts the U.S. Exclusive Economic Zone, and INPFC areas are indicated.

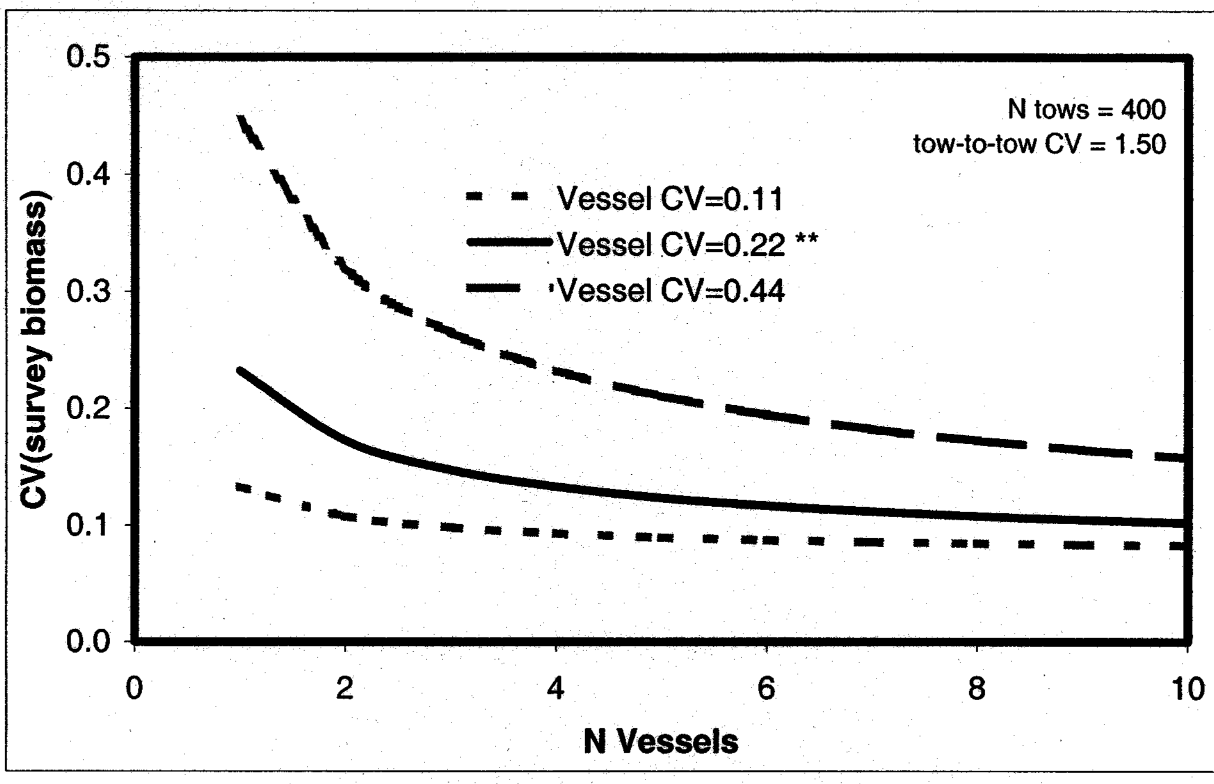

Figure 2. Results of a simulation study plotting survey biomass coefficient of variation (CV) against the number of vessels participating in a multi-vessel survey, at three levels of vessel-specific CV.

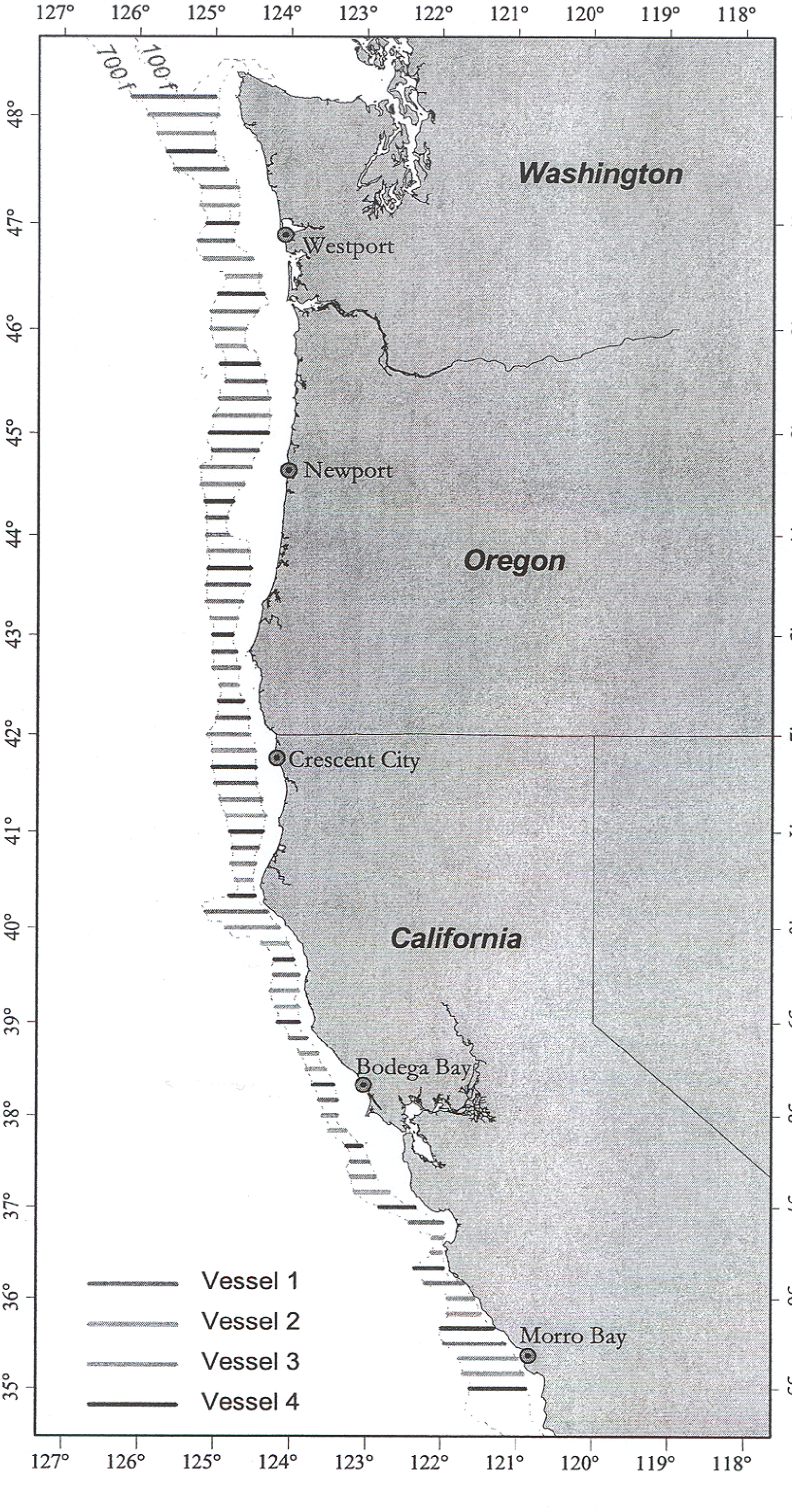

Figure 3. Layout of sampling transects occupied during the NWFSC slope survey in 1998 and 1999, with the 100-fm and 700-fm isobaths forming the east-west boundaries of each transect indicated.

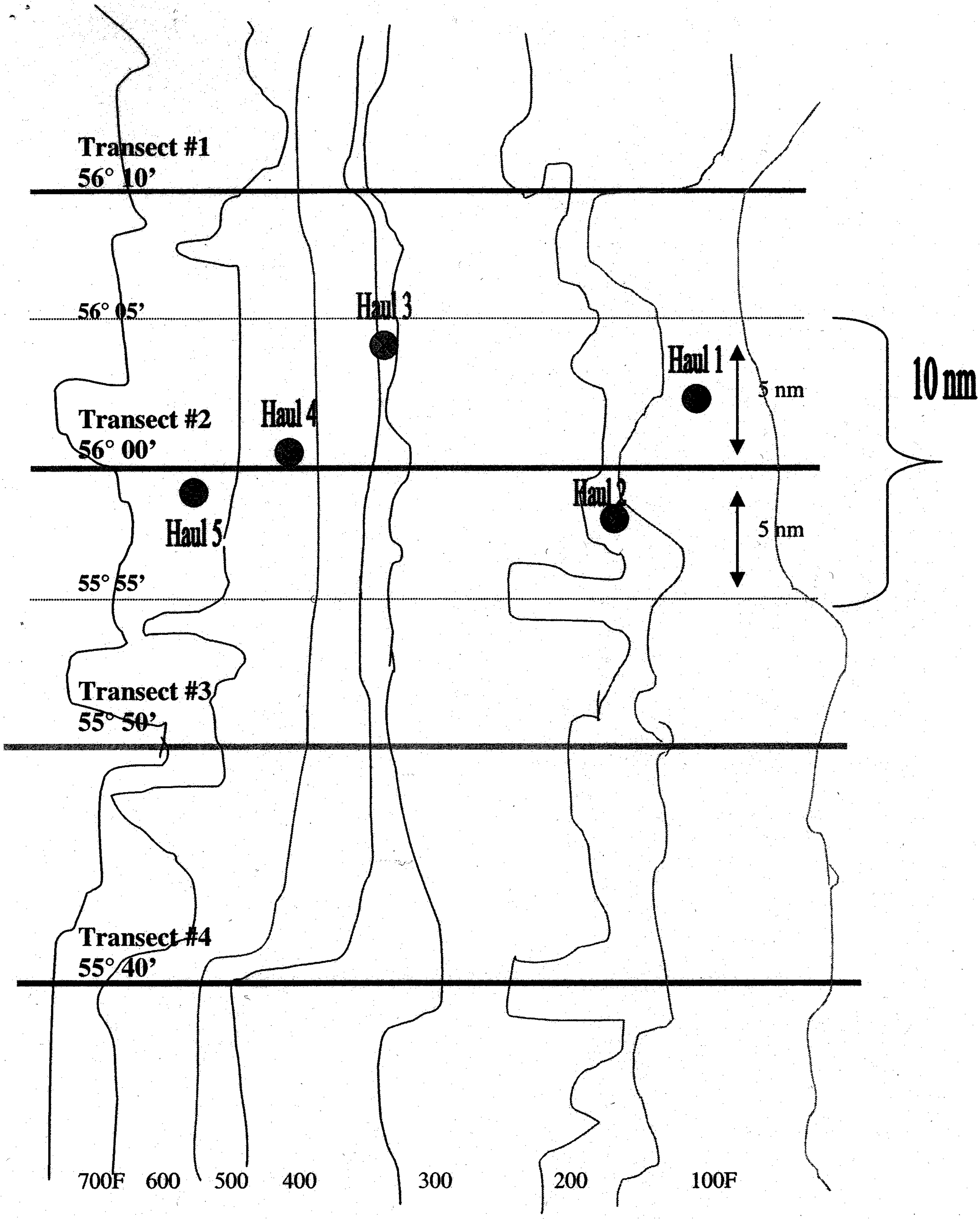

Figure 4. Example of sampling station pattern. Each transect color represents a different vessel track.