AN ABSTRACT OF THE THESIS OF

Paul R. Crone Jr. for the degree of Doctor of Philosophy in Fisheries Science presented on December 2, 1994. Title: Effects of Sampling Design, Estimators, and Variability on Groundfish Management in Oregon.

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David B. Sampson

Sampling error associated with estimates of species composition and age composition of commercial groundfish landings in Oregon from 1989 to 1991 is documented to evaluate the impact of variable landing data on fisheries management and monitoring programs. The statistical reliability and bias associated with two multistage sampling designs are investigated on the bases of the practical suitability of field procedures and accuracy and precision of the derived estimates. Additionally, the variability associated with landing estimates of age composition for five groundfish species is used to examine critically the ability of age-structured stock assessment models to describe adequately the stochastic properties of actual catch-at-age data. Finally, the spatial similarity of reproductive parameters derived from sampling data for Dover sole inhabiting marine waters off the coast of Oregon is examined in statistical and practical terms to provide management additional analyses that can be used to adopt harvest strategies that minimize detrimental effects to the exploited fish stock(s).

A two-stage random sampling design combined with stratification components generated relatively reliable landing statistics. At least two-thirds of the total landings of rockfish in each port/quarter stratum consisted of estimates of species composition that had small coefficients of variation (*CVs* <10%). For each species sampled for age composition, at least three-fourths of the total landings included estimates for individual ages with *CVs* <25%. For the majority of the landings, the variation at the first stage of sampling contributed at least 63% and 90% to the variance of the landing estimates for the species and age compositions, respectively.

An abbreviated version of a multistage sampling design, which incorporated a single sampling unit at the second stage, produced generally similar results to those generated by the 'complete' two-stage approach discussed above. However, results indicated that there was likely a substantial risk in using this design for species-composition sampling, given the biased variance measures associated with its application. For all practical purposes, the bias was not as problematic in age-composition sampling; however, caution and additional monitoring procedures are recommended to ensure that inferences reflect the actual statistical properties of the sampling design.

An analysis of the variability in catch-at-age data clearly indicated that a multinomial probability error structure, included in models that are based on maximum likelihood estimation, more closely follows the estimated variances associated with the sampled landing data than does a lognormal error structure used in models based on least squares estimation. An analysis of maturity data from commercial landings provided some statistical evidence that spatial differences may exist in sexual maturity schedules of Dover sole inhabiting Oregon waters; however, it does not appear that the statistical findings from the maturity assessments are of magnitudes that reflect dramatic implications for management.

Effects of Sampling Design, Estimators, and Variability on Groundfish Management in Oregon

by

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Paul R. Crone Jr., Author

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EFFECTS OF SAMPLING DESIGN, ESTIMATORS, AND VARIABILITY ON GROUNDFISH MANAGEMENT IN OREGON

CHAPTER 1

GENERAL INTRODUCTION

The primary objective of this study was to determine the variability associated with sample estimates of groundfish (rockfish and flatfish species) that were harvested by trawling gears and commercially landed at Oregon ports from 1989 to 1991. The appropriateness of multistage sampling designs was investigated on the bases of the practical suitability of field procedures and the accuracy and precision of the derived estimates. The statistical reliability of estimates of species and age compositions of the landings is documented and the impact of variable landing data on fisheries management and monitoring programs is addressed in this thesis.

History of the Pacific Coast Groundfish Fishery

Since the late 1800s, commercial fishers, fish processors, and public consumers of fish products have utilized the groundfish stocks (demersal or bottom fishes) off the Pacific coast of the United States as sources of income and food (Miles et al. 1982). Three periods of growth characterize the history of the Pacific coast groundfish fishery: from the late 1800s to the early 1900s, little or no management was conducted on a disorganized and relatively small commercial fishery; from the early 1900s to the early 1980s, management on a rapidly expanding fishery was the responsibility of the individual coastal states (California, Oregon, and Washington); and, currently, management on a diverse fishery and heavily exploited fish populations is coordinated by the federal government in conjunction with recommendations and support from the coastal states.

In the early 1900s, a small population base on the Pacific coast, along with a burgeoning salmon industry, resulted in only a limited market demand for groundfish (Browning 1980). During this time, groundfish were primarily harvested by small-scale commercial ventures, which used relatively simple and ineffective fish capture methods, such as paranzella nets towed from two sailboats and traditional beam and otter trawls (Alverson et al. 1964). Rapid technological advances in trawl design (in general, funnel shaped nets, which are wide at the mouth and taper back to a narrow “cod end” in which the catch collects) occurred during the late 1930s, when the United States became involved in World War II and wartime shortages of red meat created an increased demand for other sources of protein (Radtke and Davis 1993). The groundfish fishery expanded significantly from 1933 to 1945 in response to military related development along the Pacific coast and profitable fishing opportunities created by the new trawling industry (Alverson et al. 1964; Browning 1980). In 1947, the Pacific States Marine Fisheries Commission (PSMFC) was established as a non-regulatory agency, which was responsible for coordinating the independent management efforts of California, Oregon, and Washington, particularly for the fisheries that overlapped state boundaries (PFMC 1993). The PSMFC was the first formal agency to address management of the groundfish stocks throughout their entire range.

The Soviet Union and Japan exerted heavy fishing pressure on the groundfish stocks of the Pacific coast from 1950 until 1976, when the United States enacted the Magnuson Fishery Conservation and Management Act (MFCMA), which established an exclusive 200-mile coastal fishing zone (Shyam 1976; Knight 1977). This landmark legislation created regional fishery management councils, including the Pacific Fishery Management Council

(PFMC), to coordinate stock assessments on exploited fish populations and to develop fishery management plans (FMPs). From 1976 to the mid-1980s, commercial fishers from the United States took advantage of their protected fishing grounds and heavily exploited the groundfish stocks of the Pacific coast to meet the demands of flourishing export (primarily Asian countries) and domestic markets (PFMC 1993).

Annual landings of groundfish at Pacific coast ports remained relatively stable from the mid-1940s until the mid-1970s, when the yearly totals doubled from historical averages of 30,000 mt to 60,000 mt (PFMC 1993). Groundfish landings at Pacific coast ports peaked at 116,000 mt in 1982 due to newly discovered schools of widow rockfish (Gunderson 1984) and annual landings have ranged between 80,000 to 100,000 mt since then (PFMC 1993). During the mid-1980s, there was evidence that several groundfish stocks (e.g., Pacific ocean perch) were responding poorly to the high exploitation rates and their population sizes were declining rapidly. As a result, FMPs in the 1990s have largely reflected relatively conservative harvest strategies (PFMC 1993). In 1992, approximately 30,000 mt of groundfish were landed at Oregon ports, which included roughly 19,000 mt of rockfish and 11,000 mt of flatfish. It is important to note that the rapid expansion of the Pacific whiting fishery in the late 1980s produced record figures for total landings of Pacific coast groundfish during the early 1990s; however, because Pacific whiting is currently monitored and managed independently of other groundfish, it was not included in the results presented here.

Beginning in the early 1980s, the issue of effective management of the groundfish stocks inhabiting Pacific coast waters has been intensely debated by the commercial fishing industry and the government agencies responsible for the long-term welfare of marine resources (Gunderson 1984). In general, resource allocation policies have often been criticized by commercial fishery interests as being politically motivated and lacking scientific rigor (Knight 1977; Gulland 1984; Walters 1986; Hanna and Smith 1993), which has caused many fishers to view management decisions with skepticism, as too restrictive, and an infringement on their rights to pursue a profitable livelihood (Larkin 1977; Gunderson 1984; Clark 1985; Gulland 1988). The PFMC is responsible for developing fishery policies that consider conservation and economic criteria. These policies result in harvest strategies that restrict, to some degree, the revenue potential of the fishery. As the worldwide demand for fish products continues to rise, economic considerations of the groundfish fisheries will become increasingly important (Miles et al. 1982). Currently, the groundfish fishery of the Pacific coast is the largest and most important fish resource managed by the PFMC in terms of total landings and value. Since 1989, the ex-vessel value (price paid for the landed fish by the processor to the commercial fisher) of Pacific coast groundfish landings has averaged approximately $45 million per year, 60% of which was generated by Oregon landings (Radtke and Davis 1993).

For the most part, the groundfish fishery of the Pacific coast has always been managed as an 'open-access', rather than 'limited-entry' resource (PFMC 1990). That is, harvest has been regulated mainly by quota practices (e.g., limiting the total amount of a fish species that can be landed by each vessel) and various non-quota methods (e.g., area closures, legal gear definitions, minimum mesh regulations, size limits, and bag limits), rather than by restricting fishing capacity (i.e., limiting the number of fishing vessels that can operate on a fishery). The coastal states are responsible for monitoring the groundfish commercially landed at their respective ports. In general, each state independently develops sampling programs and estimation procedures for the groundfish landings, and the subsequent estimates of species and age compositions are incorporated into a regional database and provided to fishery researchers involved in stock assessment.

From the early 1900s to 1982, the management of domestic groundfish fisheries was under the jurisdiction of the states of California, Oregon, and Washington. Non-quota practices were utilized by the individual states to regulate harvest levels. In 1982 a FMP was established that dramatically changed the direction of Pacific coast groundfish management: first, the plan recognized that many groundfish stocks had ranges that crossed waters managed by more than one state and thus, it shifted primary responsibility for management from the three coastal states to a single federal agency (PFMC); and, second, quotas would be used for individual species to restrict harvest levels and prevent overfishing (PFMC 1993). The biological, sociopolitical, and economic repercussions associated with the uncontrolled increase in fishing effort during the 1980s caused the PFMC to focus attention on limiting access to the groundfish resources. The PFMC has developed experimental limited-entry programs for selected groundfish fisheries, which are scheduled to take effect in 1994 (PFMC 1993).

Sample Surveys and Stock Assessments in Fishery Management

Current stock assessment methods use estimates of species and age compositions of the landings to evaluate harvest strategies and determine appropriate quotas for commercially exploited species. The levels of exploitation, both temporally and spatially, that the groundfish stocks of the Pacific coast are able to support depend on stock assessment information that is timely and reliable. Ultimately, stock assessments rely upon the availability of appropriate data, namely sample estimates from commercial fisheries and survey information from research vessels.

Sampling the commercial landings has two advantages over collecting data from survey vessels (Pope 1988): (1) sample data from commercial landings are comparatively less expensive to collect than data obtained from research surveys; and, (2) considerably more information (e.g., larger sample sizes) can be obtained by sampling commercial landings than by conducting surveys with research vessels. However, research surveys can provide information that would be otherwise unobtainable through sampling commercial fisheries. For example, data regarding species that have no commercial market value and young fish (pre-recruit ages) of an exploited species can only be obtained using survey vessels.

Marine fishery management has relied upon two general sampling approaches to obtain catch information from commercial fisheries. One method requires sampling the catch that is landed at shoreside processing facilities by boats that have completed fishing trips. Another method requires sampling the catch that is landed on board the boats while at sea (e.g., observer programs), which allows the 'discarded' component of the catch to be assessed. Discarded fish represent that portion of the catch returned to the sea as a result of economic, legal, or personal considerations. A proportion of the discarded catch will often die as a result of harvesting and handling processes. Thus, it is generally agreed that sampling programs that are based on board fishing vessels provide the most realistic assessment of the *total* amount of fish harvested from a particular fishery (Schoning et al. 1992). However, data collection programs that are based on board fishing vessels generally are more expensive and require more demanding and elaborate field logistics than shoreside sampling designs. Historically, Pacific coast groundfish management has largely relied on sampling the shoreside landings to obtain estimates of the commercial catch and has only recently considered establishing observer programs for particular groundfish fisheries (PFMC 1993). The research presented here is based on sample data from shoreside commercial landings and does not consider survey information from research vessels or sample data from observer programs.

Although early researchers in fishery sciences alluded to the problems that variable sampling information could introduce in stock assessment (Russell 1931; Gulland 1955; Beverton and Holt 1957; Schaefer 1957; Ricker 1973, 1975), Pope and Garrod (1975) were among the first authors to more clearly define how biased and imprecise data could affect stock parameters important in the determination of fishery quotas. From a management standpoint, decisions that are based on stock assessments are associated with a level of risk, or uncertainty (Smith 1979; Peterman 1975; Brown and Patil 1986; Walters 1986; Walters and Collie 1989) that is influenced in large part by the precision associated with the sample estimates (Powles 1983). Meaningful harvest forecasts require very precise age-composition data, where coefficients of variation as small as 10% can complicate otherwise straightforward exploitation strategies (Shepherd 1988).

Rarely are management decisions dictated by a single criterion. Rather, a set of possible alternatives are evaluated and the most appropriate approach is chosen based on several factors, such as conservation of the biological resources, sociopolitical issues, and financial considerations. Coalescing this plethora of information becomes an ambitious task. To do this, fishery managers need measures of the uncertainty associated with the estimates of current conditions in order to objectively weigh the possible costs and benefits of different management policies—this information is particularly important in fisheries managed by restrictive quotas. Historically, there has been a tendency for fish stock assessment methods to treat the sample data as if they reflected exact values (in this case, point estimates from *census* data). This assumption is often inappropriate from a scientific standpoint. Results from such analyses are misleading and could be easily misinterpreted. Documenting the variability associated with the landing estimates will allow harvest strategies to be developed that reflect the amount of uncertainty in the sample data. Ultimately, accounting for sampling error is necessary to rigorously and scientifically evaluate *optimum* harvest schemes, ones that are 'sustainable' and minimize negative impacts to the fish resources.

Overview of the Thesis

The thesis is divided into four parts corresponding to the four chapters that follow. All of the results are based on variations of a two-stage random sampling design (Figure 1.1). Design evaluations were based on the statistical properties associated with variance measures of the landing estimates, particularly the relative contributions of the variability *between* primary sampling units (boat trips) versus variability between secondary sampling units (baskets of fish), *within* boat trips.

In Chapter 2, the performance of a complete two-stage sampling design is investigated. This design was employed to determine definitively the relative magnitudes of variation at the first and second stages of sampling designs used for estimating species and age compositions of the landings. Ultimately, the results presented in this chapter are used to evaluate the appropriateness of an abbreviated design addressed in Chapter 3. In particular, I assess the risk and potential repercussions in drawing inferences from biased variance information associated with the estimates of species and age compositions of the groundfish landings. Additionally, I propose schemes for sample allocation that would improve sampling efficiency and estimate precision. Chapter 2 has been accepted for publication in the *Canadian Journal of Fisheries and Aquatic Sciences*; however, the style of the chapter differs slightly from the format presented in the manuscript due to guidelines imposed by the journal.

In Chapter 3, I present estimates of variability for species and age composition information generated from an abbreviated version of the multistage design discussed in Chapter 2. The design presented in this chapter required selecting only a single sample of fish from each boat trip, which resulted in biased variance estimates that inherently ignored the variation at the second stage of sampling. This 'single-stage' approach was adopted because: (1) the design is relatively less expensive, time consuming, and complicated to employ than a 'complete' two-stage sampling plan; and, (2) fisheries management has relied on the unexamined assumption that the magnitude of variation at the second stage of the design is very small and does not warrant sampling consideration. The estimates of variability presented here and in Chapter 2 are the first documented measures of dispersion associated with age-composition sample data for Pacific coast groundfish stocks.

In Chapter 4, I evaluate the validity of assumptions regarding the stochastic properties of landing data. Many of the popular stock assessment models account for sampling error by relying on various theoretical distributions that are assumed to mimic the actual estimated variances associated with age-composition data. In Chapter 4, I use Oregon landing statistics to examine two conflicting hypotheses regarding the distributional characteristics of coefficients of variation associated with estimates of age composition.

In Chapter 5, I examine the hypothesis that Dover sole inhabiting Pacific coast waters form individual, nonintermingling 'subpopulations,' which would suggest that the species may exist as independent stocks with distinct indicators of reproduction, mortality, and physiological features, or what are commonly referred to as 'stock parameters.' In general, fish stock assessments and quota allocation programs should separately consider two or more stocks of a single species; however, independent management approaches should be adopted only after critical analysis of life history characteristics of the species generally supports the hypothesis of multiple stocks. Proper assessments can only be carried out when the biology of the species is fully understood; this information is critical to management, which largely develops harvest policies based on the growth potential of fish populations. Specifically, I evaluate statistically the spatial differences in sexual maturity schedules of Dover sole commercially landed at Oregon ports from 1989 to 1991. I use logistic regression procedures to estimate maturity rates for hypothesized 'subpopulations' along Oregon's coastline. Additionally, I qualitatively compare age-composition landing information with the derived maturity rate models and identify possible areas of overfishing suggested in the analyses.

The common and scientific names for the species of groundfish discussed in this thesis are listed in Appendix A. Complete results from analyses of species composition of rockfish landings from 1989 to 1990 are presented in tabular format in Appendix B.

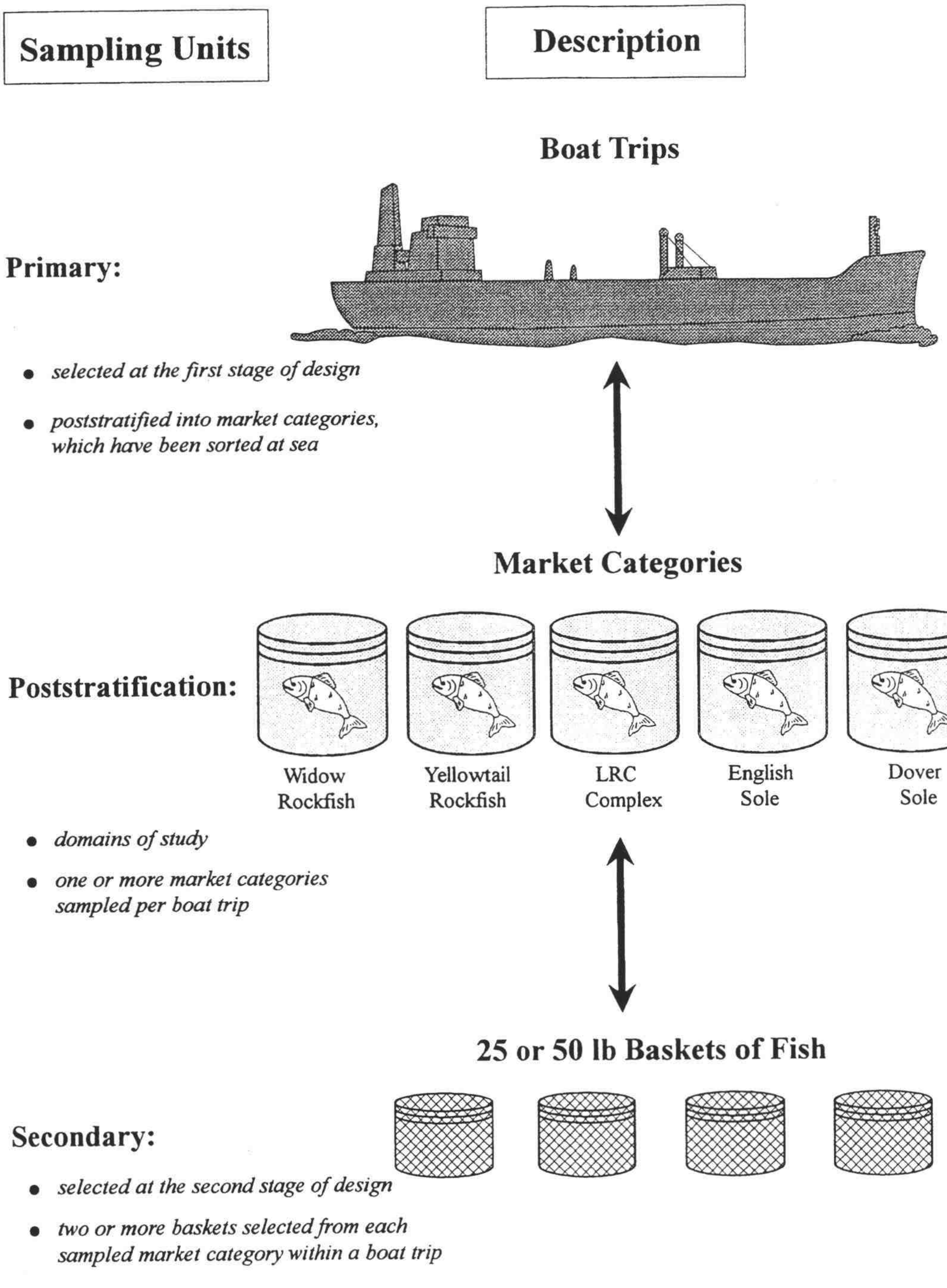

Figure 1.1. Two-stage sampling design used to monitor species and age compositions of commercially landed groundfish in Oregon (1989-1991). Port and quarter (four, three-month blocks) combinations were treated as strata. Five examples of market categories are presented. LRC Complex denotes large rockfish complex.

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CHAPTER 2

SAMPLING DESIGN AND STATISTICAL CONSIDERATIONS FOR THE COMMERCIAL GROUNDFISH FISHERY OF OREGON (1991-1992)

ABSTRACT

Fisheries management is often based on data collected through various sample survey programs. At a minimum, commercial fisheries must be monitored to determine the species and age compositions of the landings; this provides the baseline data on which to assess the stocks. An equally important objective, which is often ignored, is the determination of the variability associated with derived estimates. This paper presents measures of dispersion for landing estimates generated from a two-stage sampling design employed for commercially harvested groundfish species landed at Oregon ports. Particular attention is given to the relative magnitudes of variability at the first and second stages of sampling designs used for estimating species and age compositions of the landings. At least two-thirds of the total landings of rockfish in each port/quarter stratum consisted of estimates of species composition that had small coefficients of variation (*CVs* <10%). For each species sampled for age composition, at least three-fourths of the total landings included estimates for individual ages with *CVs* <25%. For the majority of the landings, the variation at the first stage of sampling contributed at least 63% and 90% to the variance of the landing estimates for the species and age compositions, respectively.

INTRODUCTION

The basic types of data usually regarded as necessary for current stock assessments are estimates of the species and age compositions of landings, fishing effort, and various demographic characteristics of the exploited fish populations, such as sex ratios, maturity schedules, and length distributions. To obtain these data, fishery management agencies most often monitor the commercial landings by utilizing appropriate sampling designs, which require the selection of a smaller component of a larger target population. For example, inferences about the total landings of groundfish in a specified time period (i.e., the population) can be made from information contained in a random sample of the boat-trip landings that composed the population.

Popular stock assessment models, such as virtual population analysis (Gulland 1965), cohort analysis (Pope 1983a), and stock synthesis analysis (Methot 1990) use estimates of landings and age compositions to determine the pattern of historical abundance and derive catch quotas for exploited species. The conclusions drawn from stock assessments rely largely on the reliability associated with the sampled landing data (Pope and Gray 1983; Beddington et al. 1984; Shepherd 1988; McAllister and Peterman 1992). Without estimates of the variability of the landing data, stock assessment teams must utilize input data that, at the very best, are subject to increased uncertainty and, at the worst, generate misleading results. As stock assessment techniques continue to gain acceptance in broad areas of fishery science, it becomes imperative to examine rigorously the relationship between successful management approaches and the precision and accuracy of the sampling data (Larkin 1972; Powles 1983; Pope 1988; Pelletier and Gros 1991).

In an ideal setting, the sampling of commercial landings is a routine task and appropriate designs, field protocols, and estimation procedures have been discussed in varying detail (Gulland 1955, 1966; Tomlinson 1971; Bazigos 1974; Quinn et al. 1983; Sen 1986; Pope 1988). However, in most cases, management programs are circumscribed by financial and logistical constraints, which dictate sampling methods that provide estimates of population totals, averages, and proportions, while at the same time reduce the size of the sampling operations. Additionally, the unique characteristics of many shoreside processing facilities, where sampling occurs, dictate that data collection procedures be flexible. The statistical properties of current sampling designs, particularly the precision of the landing estimates, need to be documented before alternative field and estimation techniques can be objectively evaluated.

This study addressed sampling design and statistical considerations for the commercial groundfish fishery in Oregon. The primary objective of the study was to evaluate the statistical performance of a two-stage sampling design developed by Sen (1986). In this paper, I document the sampling variability associated with the species and age compositions of groundfish landings in Oregon. Particular attention is given to the relative magnitudes of variance at the first and second stages of the sampling designs, namely the variability *between* primary units (boat trips) versus variability between secondary units (baskets of fish), *within* boat trips. Additionally, the landing statistics presented here are used to discuss the appropriateness of a sampling design, which is currently under consideration, that requires selecting only a single basket of fish within each boat trip.

METHODS

In 1989 the Oregon Department of Fish and Wildlife adopted sampling methods proposed by Sen (1986), who documented effective techniques for sampling groundfish species landed at California ports. Generally speaking, the field protocols for sampling groundfish in Oregon closely follow the data collection procedures used by the California Department of Fish and Game.

Groundfish landings in Oregon are primarily sampled to obtain estimates of species and age compositions. Sampling for species composition is required because boat-trip landings contain a mix of species that are unloaded by sort groups (market categories) rather than by individual species. In general, sort groups are determined by market demands, as well as by edicts from the Oregon Department of Fish and Wildlife. In most cases, market categories contain more than one species and the types and amount of each species contained in a market category varies between boat trips.

In this paper a 'landing' is defined as the entire amount of fish, expressed in weight or number, brought ashore by a single boat that has completed a fishing trip. The population of interest depended on the sampling objective. For species-composition sampling, the population was the total amount of rockfish harvested by trawling gears and landed at Oregon ports during the study period. For age-composition sampling, the population was the total amount of a particular species (selected rockfish and flatfish) harvested by trawling gears and landed at Oregon ports during the study period. An important feature of the sampling design was that landing estimates were based on market categories, rather than the boat trips themselves. That is, a landing was subdivided into the market categories it contained and sampling took place at the market-category level. Ultimately, the objectives of sampling were to determine: (1) species compositions of the market categories, or (2) age compositions of species of interest, which were selected from particular market categories. Methods are presented separately for the species- and age-composition sampling programs.

Species-composition Sampling Program

The analyses of species composition for this study were based on a two-stage random sampling plan combined with stratification. Port and quarter (a year partitioned into four, three-month blocks) combinations were treated as strata and boat trips within a stratum as primary sampling units; primary sampling units were selected at the first stage of the design. The boat-trip landings were poststratified into market categories. At least two baskets of fish (secondary sampling units) of a fixed weight were subsampled within each market category; the secondary sampling units were selected at the second stage of the design.

Currently, more than 20 ports along the Oregon coastline process commercially landed finfish; however, three of these ports receive nearly all of the landings and these sites are the most heavily sampled. Sampling duties are the responsibility of port biologists (samplers) assigned to the three ports: one biologist for Astoria, another for Newport, and a third biologist for Coos Bay.

Field Sampling Procedures

The following discussion is a summary of the sampling protocols used by the port biologists. Rockfish landings were sampled for species composition. The majority of the rockfish were landed in six market categories: (1) widow rockfish (WDW), (2) yellowtail rockfish (YWT), (3) Pacific ocean perch (POP), (4) thornyhead (TYH), (5) large rockfish complex (LRC), and (6) small rockfish complex (SRC). Henceforth, the three-letter acronyms are used to distinguish the market categories from the species contained within them. A boat trip could include any combination of the six market categories. Port biologists most often sampled only one market category per boat trip. However, in some cases, two and even three market categories were sampled per trip.

In general, for each market category, port biologists were instructed to obtain five boat-trip samples per 100 mt of the category landed. That is, each sample consisted of two to six baskets of fish (secondary sampling units) selected from a market category (poststratification unit) within a boat trip (primary sampling unit). Sampling protocols required at the second stage of the design were as follows: (1) two to four 11.34 kg (25 lb) baskets were taken for the WDW and TYH market categories; (2) two to four 22.68 kg (50 lb) baskets were selected for the YWT and POP market categories; (3) four to six 11.34 kg baskets were chosen for the SRC market category; and, (4) four to six 22.68 kg baskets were selected for the LRC market category. Landings were originally weighed in English units (lb) and these data were then converted to metric units (kg) for all analytical procedures.

At the processing facilities, the fish were removed from the hulls of the vessels and placed in totes (approximately 360-kg-capacity plastic, metal, or wooden bins). The totes were then either immediately transported to processing rooms (via forklifts, conveyor belts, or vacuums) or placed in a temporary cold storage room within the facility. The biologists sampled the totes while they were en route to the processing rooms, usually as the vessel was being unloaded, or while the totes were in cold storage. No single dockside sampling technique was ideal for all processing facilities. The samplers were instructed to select baskets of fish from totes separated over the entire unloading time of a vessel, e.g., a basket of fish from one of the first totes unloaded and a basket from later in the unloading operation. The individual fish selected for each basket were taken from one corner of a tote, starting at the top and working to the bottom, trying not to account consciously for sizes or species of fish selected. The samplers recorded the aggregate weights for each species contained in a basket.

Age-composition Sampling Program

The sampling design used to collect age-composition data was similar to the design presented above for species-composition sampling, but the two designs were not identical in all respects. The following discussion addresses sampling procedures unique to the age-composition sampling program.

During the study period, only landings of widow rockfish, yellowtail rockfish, canary rockfish, English sole, and Dover sole were routinely sampled for age composition. Because smaller sample sizes were allocated to the age-composition sampling program than to the species-composition sampling program, only Oregon coastwide estimates of age composition were calculated.

Sampling for age composition required selecting specimens only from certain market categories. For example, age-composition samples for yellowtail rockfish required selecting only yellowtails from the YWT market categories, and these fish were assumed to constitute random samples from the entire landings of yellowtail rockfish. This selection approach was adopted because the species involved in the age-composition sampling program were most often landed within a single market category, which was usually their own. Canary rockfish lack a market category of their own and specimens of this species were sampled only from the LRC market category, which was the category in which these rockfish were most often landed.

For each market category, port biologists were instructed to obtain two boat-trip samples per 100 mt of the category landed. Biologists most often selected two baskets of fish, of fixed weight, within each sampled market category. For widow rockfish, English sole (ENG), and Dover sole (DOV), 11.34 kg (25 lb) baskets were selected, and for yellowtail rockfish and canary rockfish, 22.68 kg (50 lb) baskets were taken. Age structures, interopercles for English sole and otoliths for all other species, were removed from the sampled fish, placed in storage vials, and examined for age determination at a later date.

Estimation Procedures

The formulae for estimators of mean and total landings and their errors documented by Sen (1984, 1986) were generally applicable to the Oregon fishery data. The formulae presented in Sen (1986) that were used in this study are relatively straightforward statistical methods used in sampling (e.g., Sukhatme and Sukhatme 1970; Cochran 1977; Scheaffer et al. 1990), which have been applied to commercial fishery data.

The statistical framework developed by Sen (1984, 1986) allowed estimation procedures to be applied similarly to samples of both species and age compositions. For a species-composition sample, the measurement variable is the weight of a particular species in a basket selected from a market category contained within a boat trip. For an age-composition sample, the measurement variable is the number of fish of a particular age in a basket selected from a market category contained within a boat trip.

The analyses of age composition for the rockfish species (widow, yellowtail, and canary rockfish) required that the market categories (WDW, YWT, and LRC) be sampled first for species composition so that the total landings of each market category, which were used as weighting variables in the estimation formulae, were appropriately adjusted to reflect the contribution of the species sampled. The ENG and DOV market categories were assumed to contain only English sole and Dover sole, respectively, thus, these categories were not sampled for species composition.

By using standard two-stage variance expressions (Cochran 1977; Scheaffer et al. 1990), the variance associated with the landing estimates was partitioned into between ($\hat{V}_{BTW}\%$) and within ($\hat{V}_{WTH}\%$) boat-trip components, which reflected variation percentages at the first and second stage of the design, respectively. Estimates of species composition and their variances were determined within market categories for each stratum (port/quarter) and then summed across market categories for calculating totals within strata. As stated previously, only Oregon coastwide estimates were generated for species included in the age-composition sampling program. I use a coefficient of variation (*CV*) as the measure of dispersion associated with a landing estimate. The *CV* was calculated as: [(standard error of the landing estimate / total landing estimate) • 100]; this statistic is also referred to as a relative standard error (Som 1973) and a coefficient of variation of the estimate (Cochran 1977).

Notation and Formulae

The notation I use follows the general style presented in Sen (1984, 1986); however, the two sets of notation are not identical in all respects, particularly subscripts associated with the various estimators. Population parameters are denoted by capital letters and sample estimators are denoted by small letters or capital letters with a circumflex.

Within a port/quarter stratum, to estimate the: (1) weight of a given species in the landings (species-composition sampling program), or (2) number of fish of a given age, for a species of interest, in the landings (age-composition sampling program), the following notation applies.

Boat trips (primary sampling units):

N_j ≡ total number of boat trips for market category j,

n_j ≡ number of boat trips sampled for market category j,

n ≡ number of boat trips sampled across all market categories,

Notes: (1) $j = 1, 2, \ldots, L$ different market categories (poststratification units) sampled. For the species-composition sampling program, most often $L = 6$, given of course that all six market categories occurred and each N_j was ≥ 2 within a port/quarter stratum. For species involved in the age-composition sampling program, $L = 1$, see Methods, Age-composition Sampling Program.

(2) In general, boat trips contained a single landing for each market category j observed, e.g., a typical boat trip may have consisted of *one* WDW market category, *one* YWT market category, and *one* THY market category.

Weight of fish:

W_{ij} $\equiv$ total weight of all fish species in market category j of boat trip i,

$W_{.j}$ $\equiv$ total weight of all fish species in market category j across all boat trips,

Note: W_{ij} and $W_{.j}$ are treated as known population parameters, i.e., values are obtained through mandatory 'fish ticket' records maintained by individual processing facilities.

w_{ijk} $\equiv$ weight of basket k sampled from market category j of boat trip i.

Baskets of fish (secondary sampling units):

M_{ij} $\equiv$ total number of baskets in market category j of boat trip i,

$M_{.j}$ $\equiv$ total number of baskets in market category j across all boat trips,

m_{ij} $\equiv$ number of baskets sampled from market category j of boat trip i.

Landing variables:

Y_{ij} $\equiv$ weight of species y landed in market category j of boat trip i (species-composition sampling program) or number of age y fish, of a particular species, landed in market category j of boat trip i (age-composition sampling program),

$Y_{.j}$ $\equiv$ weight of species y landed in market category j across all boat trips (species-composition sampling program) or number of age y fish, of a particular species, landed in market category j across all boat trips (age-composition sampling program),

$Y_{..}$ $\equiv$ total weight of species y landed across all market categories and all boat trips,

Note: For the age-composition sampling program, $L = 1$; thus, the total landing estimate across all market categories, $Y_{..}$, was not calculated, see Methods, Age-composition Sampling Program.

y_{ijk} $\equiv$ weight of species y in basket k sampled from market category j of boat trip i (species-composition sampling program), or number of age y fish, of a particular species, in basket k sampled from market category j of boat trip i (age-composition sampling program).

The following formulae for mean and total landing estimates follow Sen (1986), see section entitled Estimation Based on Categories as Domains of Study (formulae for second-stage sampling units of fixed size, pages 412-413). To accommodate sampling protocols unique to Oregon and to address assumptions regarding particular variables used in estimation procedures, I have modified slightly and present in a different form the estimated variances suggested in Sen (1986). Additionally, I discuss the applicability of selected estimators to Oregon fishery sample data where appropriate.

I present formulae and discussion that pertain to analyses of species composition; however, the estimation procedures can be applied similarly to samples of age composition. To calculate estimates of age composition, the measurement variable becomes the number of age *y* fish, of a particular species, in the landings, rather than the weight of species *y* in the landings.

The estimated mean weight of species *y* per basket in market category *j* of boat trip *i* is,

$$\overline{y}_{ij.} = \frac{\sum_{k=1}^{m_{ij}} y_{ijk}}{m_{ij}} , \tag{2.1}$$

and the ratio estimator for the mean weight of species *y* per basket in market category *j* across all boat trips is,

$$\overline{y}_{.j.} = \frac{\sum_{i=1}^{n_j} M_{ij} \overline{y}_{ij.}}{\sum_{i=1}^{n_j} M_{ij}} \cong \frac{\sum_{i=1}^{n_j} W_{ij} \overline{y}_{ij.}}{\sum_{i=1}^{n_j} W_{ij}} . \tag{2.2}$$

Equation (2.2) is a weighted estimator, where samples from boat trips with market-category landings that are large in size are given more weight in estimating $\overline{y}_{.j.}$ than boat trips with relatively small landing sizes. Given that baskets of fixed weight are selected, similar results will be obtained if the total number of baskets, M_{ij}, is used as a weighting variable for the estimator $\bar{y}_{.j.}$—this method is the standard statistical procedure used in two-stage cluster sampling designs (Sukhatme and Sukhatme 1970; Cochran 1977; Scheaffer et al. 1990).

The only practical way of determining M_{ij} is to estimate it as the total weight of market category j divided by the average weight of the baskets taken, i.e., $\hat{M}_{ij} = W_{ij} / \bar{w}_{ij.}$, where $\bar{w}_{ij.}$ is given by equation (2.5). Both empirical approaches in equation (2.2) utilize a ratio estimator, which is biased; however, the bias is negligible when n_j is large. Note, if the landing size of the market categories has no effect on the species compositions themselves, then weighting each sample mean, $\bar{y}_{ij.}$, will have little influence on the final estimates generated in equation (2.2). One advantage of using a non-weighted estimator is that the estimated variance procedures are simplified. Additionally, if a non-weighted estimator is appropriate for a two-stage sampling design and the number of secondary sampling units of fixed size is equal across the primary sampling units, then straightforward analysis of variance procedures can be utilized to derive needed statistics, such as variance of the mean, and between and within boat-trip components of variation (see sections 7.10 and 7.11 in Sukhatme and Sukhatme (1970) for a general discussion that addresses these procedures).

The estimator for the total landings, in weight, of species y in market category j is,

$$\hat{Y}_{.j} = \bar{y}_{.j.} \hat{M}_{.j} , \tag{2.3}$$

where $\hat{M}_{.j}$ is an estimate of the population total number of baskets in market category j across all boat trips ($M_{.j}$) and is calculated as $W_{.j} / \bar{w}_{.j.}$. The estimator $\bar{w}_{.j.}$ is the mean basket weight for market category j across all sampled boat trips, n_j, and is calculated as,

$$\bar{w}_{.j.} = \frac{\sum_{i=1}^{n_j} \bar{w}_{ij.}}{n_j} , \tag{2.4}$$

where $\bar{w}_{ij.}$ is the estimated mean basket weight for market category j of boat trip i and is calculated as,

$$\bar{w}_{ij.} = \frac{\sum_{k=1}^{m_{ij}} w_{ijk}}{m_{ij}} . \tag{2.5}$$

The estimator $\bar{w}_{.j.}$ may be treated as a constant if there exists very little variation in the weights of the replicate baskets selected, within similar market categories, across all of the sampled boat trips, i.e., baskets of fixed weight are selected (Sen 1986). Although the weight of the basket samples from this research varied little over the study period, $\bar{w}_{.j.}$ was calculated for each type of market category within a stratum. Estimates for $\bar{w}_{.j.}$ in each stratum were all very close to the desired basket weights of 11.34 and 22.68 kg, and all estimates were very precise, with *SDs* ≤ 0.65 kg. The estimation procedures outlined here are based on secondary sampling units of fixed size; thus, port biologists should strive rigorously to select basket weights that are as similar as possible. Violations regarding the assumption of fixed basket weights will introduce additional components of bias and variability associated with the generated statistics.

The estimator for the total landings, in weight, of species y across all market categories is,

$$\hat{Y}_{..} = \sum_{j=1}^{L} \hat{Y}_{.j} \, . \tag{2.6}$$

The estimated variance of $\bar{y}_{.j.}$ is,

$$\hat{V}(\bar{y}_{.j.}) = \left(\frac{N_j - n_j}{N_j}\right)\left(\frac{1}{n_j \hat{\hat{M}}^2_{.j}}\right) s^2_{1j} + \left(\frac{1}{n_j N_j \hat{\hat{M}}^2_{.j}}\right) \sum_{i=1}^{n_j} \hat{M}^2_{ij} \left(\frac{\hat{M}_{ij} - m_{ij}}{\hat{M}_{ij}}\right) \frac{s^2_{2ij}}{m_{ij}} \text{, where} \tag{2.7}$$

$$s^2_{1j} = \sum_{i=1}^{n_j} \hat{M}^2_{ij} \frac{(\bar{y}_{ij.} - \bar{y}_{.j.})^2}{n_j - 1} \, ,$$

$$s^2_{2ij} = \sum_{k=1}^{m_{ij}} \frac{(y_{ijk} - \bar{y}_{ij.})^2}{m_{ij} - 1} \, , \text{ and}$$

$$\hat{\hat{M}}_{.j} = \frac{\sum_{i=1}^{n_j} \hat{M}_{ij}}{n_j} \, .$$

Note that $\hat{\hat{M}}_{.j}$, the estimator for the population mean number of baskets in market category j per boat trip across all boat trips, $\bar{M}_{.j}$, is a poor statistic when: (1) there is a large amount of variation among the estimates of total number of baskets in market category j per boat trip across the entire population of boat trips (the $\hat{M}_{ij}$), and (2) very few boat trips are sampled (n_j is small); therefore, the variances themselves are subject to additional bias when these situations occur. When it is possible to ascertain population parameters, usually after the fishing season, a more appropriate estimator for the population mean number of baskets in market category j per boat trip across all boat trips would be,

$$\hat{\hat{M}}_{.j} = \left(\frac{W_{.j}}{\bar{w}_{.j.}}\right)\left(\frac{1}{N_j}\right) = \frac{\hat{M}_{.j}}{N_j} \, . \tag{2.8}$$

The estimated variance of $\hat{Y}_{.j}$ is,

$$\hat{V}(\hat{Y}_{.j}) \cong (\hat{M}_{.j})^2\, \hat{V}(\bar{y}_{.j.}) \ . \tag{2.9}$$

Formulae for $\hat{V}(\hat{Y}_{.j})$ that include expansion variables based on the total number of boat trips, N_j, rather than the estimated total number of baskets in market category j for the entire population of boat trips, $\hat{M}_{.j}$, may replace equation (2.9) when the appropriate information becomes available—these are standard methods that can be found in most general sample survey texts (e.g., Sukhatme and Sukhatme 1970; Cochran 1977; Scheaffer et al. 1990). If boat trips are randomly selected at the first stage of sampling and n_j is large, then both empirical approaches will generate similar results.

The estimated variance of $\hat{Y}_{..}$ is,

$$\hat{V}(\hat{Y}_{..}) \cong \sum_{j=1}^{L} \hat{V}(\hat{Y}_{.j}) + 2\sum_{a<b}\sum \text{COV}\,(\hat{Y}_{.a},\, \hat{Y}_{.b}) \ . \tag{2.10}$$

Landing estimates for species contained in two or more market categories sampled from the same boat trip may depend upon one another (Sen 1986); therefore, the covariance terms should be added to the summed variances in equation (2.10). If only one market category is sampled per boat trip, then the covariance terms will be zero and the issue of covarying species compositions between market categories within boat trips can be ignored (Sen 1986). The above argument is tenable if boat trips, as well as market categories within boat trips are considered independent random variables—otherwise further investigations are warranted. Where market categories are likely to be different in their species compositions and weights, as is the case with Oregon landings, a reasonable assumption is to treat the two or more sampled market categories as independent (Sen 1984; Parker and MacCall 1990). Given port biologists for Oregon have on occasion sampled more than one market category per boat trip, the issue of possible covariance was examined further. Diagnostic analyses regarding the landing observations indicated that there were no apparent linear associations between the landing estimates for species in different market categories sampled from the same boat trip. The analyses showed no evidence that the covariance term would have a significant influence on the estimated variances derived in equation (2.10). Given the above findings, equation (2.10) simplifies to,

$$\hat{V}(\hat{Y}_{..}) \cong \sum_{j=1}^{L} \hat{V}(\hat{Y}_{.j}) \ . \tag{2.11}$$

The between ($\hat{V}_{BTW}$) and within ($\hat{V}_{WTH}$) boat-trip components of $\hat{V}(\bar{y}_{.j.})$ are simply,

$$\begin{aligned} \hat{V}_{BTW} &= \left(\frac{N_j - n_j}{N_j}\right)\left(\frac{1}{n_j \hat{M}^2_{.j}}\right) s^2_{1j} \quad \text{and} \\ \hat{V}_{WTH} &= \left(\frac{1}{n_j N_j \hat{M}^2_{.j}}\right) \sum_{i=1}^{n_j} \hat{M}^2_{ij} \left(\frac{\hat{M}_{ij} - m_{ij}}{\hat{M}_{ij}}\right) \frac{s^2_{2ij}}{m_{ij}} \ , \end{aligned} \tag{2.12}$$

where s^2_{1j} and s^2_{2ij} are given by equation (2.7). The between and within boat-trip components of variation are presented in the results as percentages of $\hat{V}(\bar{y}_{.j.})$, and noted as $\hat{V}_{BTW}\%$ and $\hat{V}_{WTH}\%$, for the between and within components, respectively.

RESULTS

Results are presented separately for the species- and age-composition sampling programs. Estimates of species composition are presented as weight (in kg) of fish landed and estimates of age composition are presented as numbers of fish landed.

Species-composition Sampling Program

Species-composition data collected from August 1991 through March 1992 were analyzed in this study. Results from analyses of completely sampled quarters are presented here, namely 4th quarter (October - December) 1991 and 1st quarter (January - March) 1992. Results are based on analyses of six port/quarter strata; two quarters for each of the three ports. General patterns for landing estimates and their errors that existed across the strata are presented. Additionally, results for Newport/1st quarter 1992 are used to illustrate the statistical properties of the rockfish landings for a typical and complete stratum.

The LRC market category in each stratum always contained only a single species, canary rockfish, that composed greater than 25% of the total landings. For example, in a stratum, canary rockfish never composed less than 35,012 kg or more than 193,890 kg and never less than 28% or more than 93% of the LRC market category (Table 2.1). The *CV* of the estimates for canary rockfish landed in the LRC market category ranged from 8 to 41%; however, most often these landing estimates for canary rockfish were relatively precise, with *CVs* <15%. The remaining species composition for the LRC market category in each stratum included from 6 to 20 species that individually contributed less than 18% to the total landings and the *CV* of the landing estimates for these species ranged from 20 to 143% (Table 2.1); however, most often these landing estimates were highly variable (*CVs* >50%).

The SRC market category in each of the six strata always contained one or two species (yellowmouth and/or darkblotched rockfish) that composed greater than 25% of the total landings (Table 2.1). The *CV* of the landing estimates were fairly large (22 to 35%) for species that contributed greater than 25% to the total landings of the SRC market category. In cases (strata) where darkblotched and yellowmouth rockfish individually composed less than one-fourth of the total landings of the SRC market category the landing estimates were highly variable, with *CVs* that ranged from 58 to 73%. The species composition of the SRC market category in each stratum contained from 16 to 18 additional rockfish species that individually composed less than 20% of the total landings and had estimates that were highly variable, where *CVs* ranged from 23 to 121%, with the majority greater than 40%.

The TYH market category in each stratum always consisted only of shortspine and longspine thornyhead (Table 2.1). The estimates for thornyhead spp. landed in the TYH market category were very precise (*CVs* <15%) in cases, four of the six strata, where these species composed at least one-third of the total landings.

The POP, YWT, and WDW market categories contained primarily of their own species, namely Pacific ocean perch, yellowtail rockfish, and widow rockfish, for the three market categories, respectively (Table 2.1). The landing estimates for these species within their respective market categories were very precise, with *CVs* always $\leq 1\%$. For two of the six strata, the YWT and WDW market categories contained only their own species (yellowtail and widow rockfish, respectively), which resulted in *CVs* = 0%. In cases where the POP, YWT, and WDW market categories did include additional rockfish, from one to five species individually composed less than 1% of the total landings and had highly variable landing estimates, with *CVs* that ranged from 54 to 113%.

In general, most of the variability associated with landing estimates for individual species was due to the between boat-trip component of variation ($\hat{V}_{BTW}\%$); however, the magnitude of $\hat{V}_{BTW}\%$ was not consistent across all of the market categories. That is, the variation within boat trips ($\hat{V}_{WTH}\%$) was large enough to warrant consideration in some situations. With the exception of the species landed in the SRC market category, $\hat{V}_{BTW}\%$ composed at least 63% of the estimated variance of the landing estimates for the individual species (Figure 2.1). The SRC market category was the only category in which landing estimates were characterized by substantial amounts of second-stage sampling error ($\hat{V}_{WTH}\%$). In general, $\hat{V}_{BTW}\%$ was the highest and most consistent (i.e., generated narrow ranges) for species landed in the LRC, TYH, and WDW market categories, where at least 80% of the estimated variance associated with these landing estimates was due to the variation at the first stage of sampling. In general, the POP and YWT market categories were characterized by landing estimates with $\hat{V}_{BTW}\%$ values that were slightly lower and less consistent (i.e., generated wider ranges) than those observed for species landed in the LRC, TYH, and WDW market categories.

In each stratum, at least two-thirds of the total landings of rockfish consisted of from three to five species that had very precise landing estimates, with *CVs* <10%. There were six species that were estimated with high precision (*CV* <10%) in at least one stratum (Table 2.2). With the exception of canary rockfish, which was primarily landed in the LRC market category, all of the species that had precise estimates were primarily landed in their own market categories. The remaining species composition of each stratum included rockfish that were landed mostly in the LRC and SRC market categories and these landing estimates were highly variable, with *CVs* that ranged from 20 to 121% (Table 2.2), the majority of which were greater than 40%. For example, yellowtail rockfish, which was primarily landed in the YWT market category, composed from 5 to 38% of the total landings in each stratum and was always estimated with very high precision, whereas darkblotched rockfish, which was primarily landed in the LRC and SRC market categories, composed from 2 to 8% of the total landings in each stratum and was never measured with high precision (Table 2.2).

The estimates for Newport/1st quarter 1992 (Table 2.3) were typical of the general characteristics of species composition presented above (Tables 2.1 and 2.2, Figure 2.1). The LRC and SRC market categories consisted primarily of species that were not not estimated with high precision. Canary rockfish, which composed over one-half of the LRC market category, was the only species landed in either of the complex market categories that had a *CV* of the landing estimate less than 15%.

The TYH, POP, YWT, and WDW market categories consisted primarily of their own species, namely thornyhead spp., Pacific ocean perch, yellowtail rockfish, and widow rockfish, for the four market categories, respectively (Table 2.3). With the exception of shortspine thornyhead, which composed less than 10% of the TYH market category, all of the above species were estimated with very high precision, with *CVs* <10%. The other rockfish landed in these four market categories had estimates that were highly variable, with *CVs* >55%.

For the Newport/1st quarter 1992 stratum, at least 70% of the variance associated with the estimated landings for species in the LRC, TYH, POP, YWT, and WDW market categories was due to variation between boat trips, $\hat{V}_{BTW}\%$, (Table 2.3). The estimated variances associated with landings of darkblotched and yellowmouth rockfish in the SRC market category, which together composed roughly 70% of the total landings, were also primarily due to $\hat{V}_{BTW}\%$; however, the remaining 30% of the species composition included landing estimates with variances that incorporated considerable amounts of second-stage sampling error ($\hat{V}_{WTH}\%$).

Approximately 90% of the total landings for the Newport/1st quarter 1992 stratum included species that had precise landing estimates, with *CVs* $\leq$12% (Table 2.4). With the exception of canary rockfish, which was primarily landed in the LRC market category (Table 2.3), the species that composed the precise landing information were landed in their own market categories. The remaining 14 species were primarily landed in the LRC and

SRC market categories and had landing estimates that were highly variable, where *CVs* ranged from 20 to 83%, the majority of which were greater than 40%.

Age-composition Sampling Program

Age-composition data collected from January to December 1991 were analyzed for this study. In general, age-composition statistics were very consistent for all five species analyzed. Additionally, results from analyses of yellowtail rockfish are presented to highlight the general discussion and illustrate the statistical properties of a typical and complete age composition of a species.

For the most part, results from age-composition analyses were more variable, albeit slightly, than landing estimates of species composition. That is, the percentage of the age composition of each species that included landing estimates with *CVs* <10% was smaller than the percentage of the total landings of each stratum that consisted of precise estimates of species composition.

All five species were characterized by a relatively small range of consecutive ages that together composed the majority of the total landings (Table 2.5). At least 89% of the total landings of each species included ages that individually contributed greater than 1% to the total landings and, for the most part, these estimates were relatively precise, with *CVs* ≤25%. The remaining 4 to 11% of each age composition consisted of 9 to 28 ages that individually contributed ≤1% to the total landings, with from one to three younger ages preceding and from 8 to 25 older ages following the group of ages that constituted the majority. In general, for all species, highly variable landing estimates characterized the ages that constituted ≤1% of the total landings, with *CVs* usually greater than 40%.

For each species, landing estimates for individual ages had estimated variances that were almost due entirely to variation between boat trips ($\hat{V}_{BTW}\%$). For all five species analyzed, at least 90% of the variance of the landing estimate for each age in the composition was due to $\hat{V}_{BTW}\%$.

Estimates of age composition for yellowtail rockfish landed at Oregon ports in 1991 were typical of the general age-composition results (Table 2.6). Fish from ages 6 to 17 composed roughly 94% (1,245,053 fish) of the total landings of yellowtail rockfish and the landing estimates for the individual ages were relatively precise, with *CVs* $\leq$25%. The remaining approximately 6% of the age composition included 21 ages that individually did not contribute more than 1% to the total landings and these estimates were generally more variable than those ages associated with the 94% majority. At least 96% of the variance of the landing estimate for each age was due to differences between the sampled boat trips at the first stage of sampling ($\hat{V}_{BTW}\%$).

DISCUSSION

The sampling designs used in this research provided effective methods for sampling groundfish landings in Oregon. In general, the designs generated relatively precise results; however, the statistical properties of the landing estimates were not identical between the species- and age-composition sampling programs, which in effect, produced different conclusions in some cases. The most important difference between the results generated from the two analyses was the magnitude and consistency of the variation at the second stage of sampling ($\hat{V}_{WTH}\%$). The impact of the variability at the second stage of sampling is of particular importance presently, because time and financial constraints have caused Oregon and California groundfish management to consider less rigorous sampling protocols than those currently in use. Investigations regarding the benefits and costs of selecting only a single basket of fish within each sampled boat trip have been proposed as research areas that need to be addressed so that revisions to current designs can be evaluated appropriately (U.S. Pacific Coast Groundfish Statistics Working Group, D. B. Sampson (Chairperson), personal communication).

Considerable amounts of second-stage variation characterized substantial portions of the species-composition results. In particular, the species that contributed small percentages (<1%) to the total landings of each market category and most of the species landed in the SRC market category had estimated variances that were due, in large part, to sampling error at the second stage of sampling. The species-composition results clearly indicate that a modified version of the current design, one that requires only a single basket of fish at the second stage, will produce seriously biased variance estimates in many cases. It may be valid in some cases to assume that the variation within a boat trip ($\hat{V}_{WTH}\%$) is insignificant and does not warrant sampling consideration; however, where and when this is true cannot be predicted. The results presented here indicate that selecting two baskets of fish from a market category within a boat trip would provide relatively reliable and accurate sampling information for the majority of the rockfish landings, and that taking more than two baskets of fish will have little influence on the final variance estimates. If selecting and recording a second basket causes a port biologist to forgo sampling other boat trips, then a trade-off between accuracy and precision of the landing statistics may need further evaluation.

Results from age-composition analyses provide some evidence that an abbreviated version of the complete two-stage sampling approach, one based on a single basket of fish at the second stage, could be used without compromising the validity of the landing estimates. For each species in the age-composition sampling program, at least 90% of the variance associated with the landing estimates for individual ages was due to variability between boat trips ($\hat{V}_{BTW}\%$) and very little variation existed between baskets of fish selected within each boat trip ($\hat{V}_{WTH}\%$). Although selection of single baskets of fish from the sampled boat trips would result in biased variance estimates, the bias may not be important for all practical purposes. This finding is likely to be of considerable benefit to this, as well as other age-composition sampling programs, which usually take a considerable amount of time in the field because of the technical difficulty of removing age structures from the individual fish.

It should be emphasized that whenever possible a second basket of fish should be selected to ensure unbiased variance estimates. If it is decided that the selection of a single basket of fish at the second stage of the design is appropriate, then I recommend that a short-term, complete two-stage design be used periodically to validate that $\hat{V}_{WTH}\%$ is inconsequential for management concerns.

In general, variance estimates associated with landing estimates from the species- and age- composition sampling programs included relatively small amounts of second-stage variation; therefore, a maximum of two baskets of fish should be selected within each sampled market category. The only possible exception to this recommendation would be subsampling procedures within the SRC market category, where the selection of three to four baskets of fish may be warranted in some situations, depending on the strata of interest and sampling objectives. Future design investigations regarding optimum sampling and subsampling fractions, ones that consider sampling costs, would provide information on efficient sample size allocations.

It is important to note that the designs used in this study for the species- and age-composition sampling programs did not utilize 'random' selection protocols for boat trips, market categories, or baskets of fish. That is, port samplers arbitrarily chose the sampling units at each stage of the design based on suggested sampling rates. This design is commonly referred to as 'quota' sampling. This purposive method of selecting samples is used in most commercial fishery monitoring programs and is a difficult problem to circumvent (Tomlinson 1971; A. R. Sen, The University of Calgary, Department of Mathematics and Statistics, personal communication).

It is evident from sampling theory that the results generated from nonprobability sampling have no definable way of being evaluated statistically, because it is not possible to construct a probability distribution for the sample and thus, the variance of the landing estimates cannot be determined. The issue of nonrandom sampling in commercial fisheries is most often circumvented by assuming that boats arrive at a port in a random manner and any selection thereof will produce samples that can be treated as random units. The appropriateness of this assumption could be evaluated by comparing easily obtained characteristics of sampled and unsampled boat trips, such as fishing locales, gears used, and types and total weights of market categories landed. The purpose of these comparisons is not to support or falsify the hypothesis that the selection process generates random samples (i.e., samples are not selected randomly), but rather to provide information that can be used to address qualitatively the extent of possible selection biases, and assess whether the boat-trip samples are representative of the population of boat trips and the assumption of random sampling is reasonable.

The variability of the landing data utilized in stock assessments has received sparse attention in fisheries management (Doubleday 1983), most likely because the inclusion of uncertainty terms at the estimation stage results in a more complicated analysis. Because landing estimates are most often based on data from a subset of a population, there necessarily exist discrepancies, or sampling error, between the sample estimates and the population parameters of interest. There is a tendency, many times unjustified, in stock assessment to treat sample estimates as if they were exact values that had been calculated from census data. This is in part due to the lack of information that exists regarding variance measures for landing estimates of individual species, which are not, as a general rule, derived and made available to a researcher interested in the status of a particular fish stock.

Recognition of the sampling error, or uncertainty, associated with the landing data is necessary if realistic and scientific inferences are to be used to establish monitoring policies. That is, interval estimation techniques, rather than point estimation methods, are appropriate for landing estimates that are based on sampling efforts. For example, the *CV* of 8% associated with the Pacific ocean perch landing estimate of 21,640 kg (Table 2.4) translates to a 75% confidence interval (*CI*) approximately equal to 18,178 to 25,102 kg. This conservative *CI* was obtained using Tchebysheff's theorem, which states that at least 75% of the observations for any probability distribution will be within two standard deviations of their mean (Scheaffer et al. 1990). Note that the confidence level above is much higher (95%) if the sampling distribution of this sample quantity, or any other, is assumed to follow approximately a normal distribution. The determination of *CIs* is particularly important when the species being monitored are allocated to the fishers by means of restrictive quotas, as is the case with Pacific ocean perch, which are currently part of a long-term rebuilding plan. There are other statistical techniques for calculating confidence intervals around sample estimates that are appropriate as well, such as bootstrap analysis (Efron 1982), which has been used to bound catch-per-unit-effort estimates for commercial fisheries (Kimura and Balsiger 1985; Stanley 1992). Regardless of the method used to determine the bound on the error of estimation, each constructed confidence interval can be practically interpreted as an interval estimate of the true population parameter.

A logical first step in determining appropriate quota levels (e.g., Acceptable Biological Catch, ABC, or Total Allowable Catch, TAC) is to document the variability associated with landing estimates that are based on sample data. Subsequently, this aspect of uncertainty connected with the quota estimation process should be considered, at the very least in qualitative terms, during the decision-making process. For example, management decisions could account for sampling variability and provide stock abundance predictions that are more general, such as proposed quotas that are associated with 'low, moderate, or high risk outcomes' versus statistical probability measures. Research oriented towards analytical treatment of sampling variability in stock assessment models is in its incipient stages and will most likely be an area of important consideration in future fishery work. Researchers in stock assessment would be remiss, in the most benign circumstances, to assume that the error associated with the sampling data can be ignored without any detrimental effects to the long-term welfare of fish stocks.

The results from this study provide the first measures of error associated with species- and age-composition estimates of Oregon groundfish landings. Additionally, variance estimates of age composition presented here represent, for the most part, the only measures of dispersion currently available to stock assessment teams interested in Pacific coast fish stocks. Finally, this study documents the broader application of a sampling design developed for a particular fishery (Sen 1986). This final area of significance is a very important issue that concerns multiple fisheries that are managed jointly, but are not subjected to similar sampling approaches. In general, the Pacific coast states (California, Oregon, and Washington) independently develop and conduct sampling programs for groundfish stocks landed at their respective ports. The states provide estimates of species and age compositions to a central management agency, the Pacific Fishery Management Council. Groundfish stock assessments are coordinated through the Council, which relies on federal, state, and academic scientists to carry out research programs. The intricacies of such a management process often result in available data that are difficult to decipher and review critically. This paper provides evidence that it may be possible to standardize, to some degree, the individual monitoring programs used to sample groundfish landed at Pacific coast ports, which would benefit the stock assessment research conducted on this resource, as well as provide other researchers with databases that can be more readily accessed and interpreted than currently available.

Table 2.1. Species-composition summaries by market category for rockfish landings in Oregon, October 1991 - March 1992. Ranges for landing estimates (in kg), percent of market-category total landings, and *CV* are based on species-composition results for market categories within six port/quarter strata. For each market category, rockfish species are listed in descending order according to maximum percent contribution to market-category total landings.

		Range [a]		
Market category [b]	Rockfish species	Landing estimate ($\hat{T}_{.j}$)	Percent of market-category total landings	*CV* (%)
LRC	Canary	35,012 - 193,890	28 - 93	8 - 41
	Bocaccio	0 - 35,960	0 - 18	25 - 84
	Darkblotched	2,413 - 26,127	2 - 18	40 - 123
	Shortraker	0 - 39,216	0 - 15	49 - 69
	Yellowmouth	0 - 23,125	0 - 12	27 - 58
	Rougheye	235 - 30,024	<1 - 12	20 - 120
	Yelloweye	0 - 9,627	0 - 11	42 - 119
	Splitnose	0 - 9,242	0 - 7	44 - 82
	Redstripe	0 - 8,450	0 - 4	49 - 83
	Chilipepper [c]	0 - 3,450	0 - 4	103
	Bank	0 - 6,873	0 - 3	71 - 88
	Redbanded	0 - 8,426	0 - 3	64 - 110
	Sharpchin	0 - 7,862	0 - 3	44 - 70
	Silvergrey	74 - 4,179	<1 - 3	37 - 113
	Aurora	0 - 5,333	0 - 2	57 - 104
	Pacific ocean perch	500 - 3,557	<1 - 2	51 - 118
	Greenstriped	0 - 2,810	0 - 1	50 - 100
	Miscellaneous [d]	38 - 1,325	<1	54 - 143
SRC	Yellowmouth	0 - 119,041	0 - 63	22 - 73
	Darkblotched	13,521 - 37,690	20 - 47	22 - 58
	Redstripe	177 - 8,943	<1 - 20	30 - 101
	Sharpchin	246 - 14,953	<1 - 20	39 - 69
	Greenstriped	172 - 5,584	<1 - 13	40 - 117
	Pacific ocean perch	2,502 - 6,241	3 - 8	23 - 47
	Canary	0 - 4,055	0 - 8	28 - 110
	Splitnose	823 - 5,400	1 - 8	34 - 42
	Rougheye	116 - 7,642	<1 - 5	25 - 109
	Yelloweye	0 - 2,163	0 - 2	46 - 87
	Bocaccio	0 - 1,105	0 - 2	58 - 116
	Bank	0 - 2,971	0 - 2	48 - 102
	Redbanded	0 - 1,189	0 - 2	60 - 121
	Aurora	89 - 2,769	<1 - 1	27 - 102
	Rosethorn	35 - 537	<1 - 1	57 - 70
	Miscellaneous [d]	9 - 551	<1	46 - 116

Table 2.1. (*Concluded*)

		Range [a]		
Market category [b]	Rockfish species	Landing estimate ($\hat{T}_{.j}$)	Percent of market-category total landings	*CV* (%)
TYH	Shortspine thornyhead	15,820 - 269,053	9 - 92	7 - 61
	Longspine thornyhead	23,429 - 287,594	8 - 91	6 - 58
POP	Pacific ocean perch	16,883 - 28,276	98 - 99	<1 - 1
	Miscellaneous [d]	9 - 253	<1	54 - 113
YWT	Yellowtail	47,388 - 580,767	99 -100	0 - 1
	Miscellaneous [d]	24 - 1,208	<1	64 - 108
WDW	Widow	40,064 - 516,605	99 -100	0 - 1
	Miscellaneous [d]	581 - 2,459	<1	60 - 102

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[a] Ranges for landing estimates and percent of market-category total landings that include zero indicate the rockfish species was not landed in the noted market category of all six strata. Ranges for *CV* are based on market categories of strata that rockfish species were landed in.

[b] Market-category acronyms are as follows: LRC is large rockfish complex, SRC is small rockfish complex, TYH is thornyhead, POP is Pacific ocean perch, YWT is yellowtail rockfish, and WDW is widow rockfish.

[c] Chilipepper was landed in the LRC market category of only one stratum, thus, a single *CV* estimate is presented.

[d] Miscellaneous includes rockfish species that composed <1% of the total landings (in weight) of a market category in at least one stratum: 6 species in LRC, 12 in SRC, 4 in POP, 6 in YWT, and 2 in WDW.

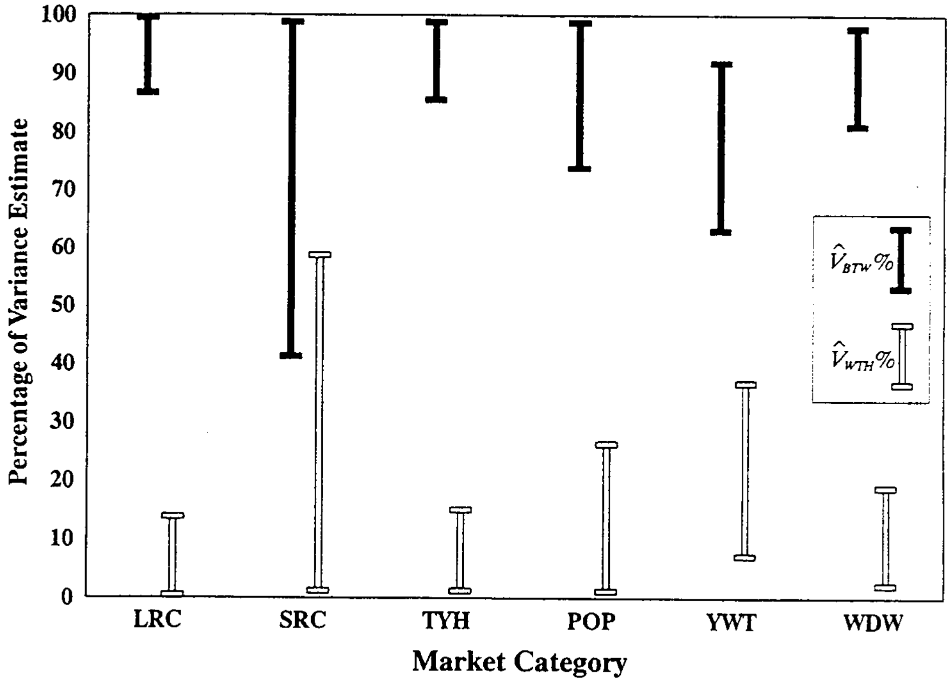

Figure 2.1. Ranges for between ($\hat{V}_{BTW}\%$) and within ($\hat{V}_{WTH}\%$) boat-trip components of variation, expressed as percentages of the total variance estimates, associated with rockfish landings in six market categories across six port/quarter strata (October 1991 - March 1992). Only landing estimates that had *CVs* >1% are included in the ranges. Market-category acronyms are as follows: LRC is large rockfish complex, SRC is small rockfish complex, TYH is thornyhead, POP is Pacific ocean perch, YWT is yellowtail rockfish, and WDW is widow rockfish.

Table 2.2. Species-composition summary for total rockfish landings in Oregon, October 1991 - March 1992. Ranges for landing estimates (in kg), percent of stratum total landings, and *CV* are based on species-composition results for six port/quarter strata.[a] Rockfish species are listed in descending order according to maximum percent contribution to stratum total landings.

	Range[b]		
Rockfish species	Landing estimate $(\hat{T}_{..})$	Percent of stratum total landings	*CV* (%)
Yellowtail	47,388 - 584,122	5 - 38	0 - 1
Widow	40,144 - 517,813	4 - 34	0 - 1
Shortspine thornyhead	15,830 - 269,147	1 - 34	7 - 61
Longspine thornyhead	23,429 - 287,594	3 - 31	6 - 58
Canary	65,774 - 194,009	7 - 21	7 - 13
Yellowmouth	0 - 139,901	0 - 18	20 - 66
Darkblotched	15,934 - 63,816	2 - 8	20 - 39
Pacific ocean perch	3,002 - 34,784	<1 - 4	5 - 44
Bocaccio	0 - 37,011	0 - 2	25 - 84
Rougheye	351 - 16,679	<1 - 2	42 - 105
Sharpchin	1,677 - 14,953	<1 - 2	43 - 65
Redstripe	1,483 - 10,014	<1 - 1	46 - 69
Splitnose	857 - 9,076	<1 - 1	35 - 49
Miscellaneous[c]	15 - 10,685	<1	27 - 121

[a] Stratum landing estimates for rockfish species were calculated by simply summing market-category estimates within strata (see Estimation Procedures).

[b] Ranges for landing estimates and percent of stratum total landings that include zero indicate the rockfish species was not landed in all six strata. Ranges for *CV* are based on strata that rockfish species were landed in.

[c] Miscellaneous includes 15 rockfish species that always composed <1% (in weight) of the total landings of a stratum.

Table 2.3. Species-composition estimates by market category for the Newport/1st quarter 1992 stratum. Landing estimates are in kilograms of fish. Between ($\hat{V}_{BTW}\%$) and within ($\hat{V}_{WTH}\%$) boat-trip components of variation are expressed as percentages of the estimated total variance of the landing estimates.

Market category [a]	Rockfish species	Landing estimate ($\hat{t}_{.j}$)	Percent of market-category total landings	$\hat{V}_{BTW}\%$	$\hat{V}_{WTH}\%$	CV (%)
LRC	Canary	103,264	52	94	6	12
n_j [b] = 13	Bocaccio	35,960	18	97	3	25
	Yellowmouth	23,125	12	98	2	58
	Yelloweye	9,627	5	98	2	51
	Redstripe	8,450	4	99	1	53
	Bank	6,873	3	90	10	88
	Darkblotched	3,093	2	96	4	46
	Silvergrey	2,460	1	87	13	62
	Pacific ocean perch	2,111	1	92	8	77
	Rougheye	1,295	<1	97	3	104
	Splitnose	1,107	<1	99	1	82
	Sharpchin	1,041	<1	93	7	58
	Yellowtail	735	<1	86	14	57
	Greenstriped	228	<1	100	0	100
	Rosethorn	44	<1	88	12	86
	Subtotal	199,413	100			
SRC	Darkblotched	20,241	38	97	3	22
n_j = 13	Yellowmouth	17,353	33	97	3	26
	Canary	4,055	8	68	32	28
	Pacific ocean perch	2,646	5	83	17	24
	Rougheye	2,373	5	41	59	32
	Greenstriped	1,146	2	94	6	55
	Yelloweye	1,058	2	79	21	46
	Bocaccio	1,051	2	64	36	58
	Splitnose	823	2	70	30	34
	Redstripe	733	1	72	28	30
	Silvergrey	519	<1	54	46	46
	Bank	406	<1	64	36	48
	Sharpchin	246	<1	74	26	39
	Aurora	219	<1	74	26	47
	Yellowtail	161	<1	57	43	86
	Rosethorn	35	<1	43	57	70
	Shortspine thornyhead	31	<1	43	57	100
	Subtotal	53,096	100			

Table 2.3. (*Concluded*)

Market category [a]	Rockfish species	Landing estimate ($\hat{t}_{.j}$)	Percent of market-category total landings	$\hat{V}_{BTW}\%$	$\hat{V}_{WTH}\%$	*CV* (%)
TYH	Longspine thornyhead	158,805	91	99	1	6
n_j [b] = 5	Shortspine thornyhead	15,820	9	99	1	61
	Subtotal	174,625	100			
POP	Pacific ocean perch	16,883	99	73	27	1
$n_j = 5$	Aurora	121	<1	75	25	56
	Yellowmouth	61	<1	90	10	82
	Splitnose	9	<1	92	8	113
	Subtotal	17,074	100			
YWT	Yellowtail	580,767	>99	75	25	1
$n_j = 30$	Widow	1,208	<1	86	14	64
	Redstripe	503	<1	70	30	74
	Sharpchin	390	<1	70	30	99
	Subtotal	582,868	100			
WDW	Widow	516,605	>99	85	15	1
$n_j = 38$	Yellowtail	2,459	<1	88	12	60
	Subtotal	519,064	100			
	Total	1,546,140				

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[a] Market-category acronyms are as follows: (1) LRC is large rockfish complex, (2) SRC is small rockfish complex, (3) POP is Pacific ocean perch, (4) WDW is widow rockfish, (5) YWT is yellowtail rockfish, and (6) TYH is thornyhead.

[b] n_j is the sample size.

Table 2.4. Species-composition estimates for the Newport/1st quarter 1992 stratum. Landing estimates are in kilograms of fish.

Rockfish species	Landing estimate ($\hat{T}_{..}$)	Percent of stratum total landings	*CV* (%)
Yellowtail	584,122	38	1
Widow	517,813	33	1
Longspine thornyhead	158,805	10	6
Canary	107,319	7	12
Yellowmouth	40,539	3	35
Bocaccio	37,011	2	25
Darkblotched	23,334	2	20
Pacific ocean perch	21,640	1	8
Shortspine thornyhead	15,851	1	61
Yelloweye	10,685	<1	46
Redstripe	9,686	<1	46
Bank	7,279	<1	83
Rougheye	3,668	<1	42
Silvergrey	2,979	<1	52
Splitnose	1,939	<1	49
Sharpchin	1,677	<1	43
Greenstriped	1,374	<1	49
Aurora	340	<1	36
Rosethorn	79	<1	57
Total	1,546,140	100	

Table 2.5. Age-composition summaries for groundfish landings in Oregon, January - December 1991. Landing estimates are in number of fish.

Groundfish species	Age	Landing estimate $(\hat{T}_{.j})$	Percent of total landings	*CV* (%)
Yellowtail rockfish	5	3,166	<1	82
n_j[a] = 35	6	41,245	3	24
	7	204,751	16	23
	8	194,155	15	18
	9	121,146	9	23
	10	176,841	13	10
	11	106,203	8	9
	12	78,627	6	15
	13	81,901	6	21
	14	77,285	6	14
	15	79,947	6	25
	16	44,328	3	15
	17	38,624	3	23
	18 - 59[b]	234 - 15,857	≤1	28 - 104
	Total	1,313,938	100	
Widow rockfish	4	614	<1	74
n_j = 138	5	64,782	2	19
	6	527,588	13	9
	7	759,068	18	8
	8	647,342	15	6
	9	553,047	13	6
	10	787,852	19	5
	11	365,825	9	8
	12	126,240	3	15
	13	124,780	3	13
	14 - 39[b]	131 - 44,944	≤1	21 - 106
	Total	4,200,305	100	
Canary rockfish	5	5,417	1	60
n_j = 17	6	15,907	2	35
	7	50,470	5	33
	8	105,234	11	17
	9	136,758	14	17
	10	114,148	12	16
	11	115,578	12	15
	12	104,466	11	11
	13	57,136	6	14
	14	44,672	5	17
	15	43,621	5	23
	16	17,206	2	33

Table 2.5. (*Concluded*)

Groundfish species	Age	Landing estimate ($\hat{T}_{.j}$)	Percent of total landings	*CV* (%)
	17	16,164	2	47
	18	19,640	2	29
	19 - 41[b]	173 - 12,139	≤1	41 - 108
	Total	945,389	100	
English sole	2	37,561	1	63
n_j[a] = 14	3	119,995	5	36
	4	316,421	12	25
	5	513,598	20	17
	6	851,558	34	13
	7	484,051	19	12
	8	98,367	4	16
	9	51,100	2	22
	10 - 23[b]	422 - 24,919	≤1	53 - 108
	Total	2,532,791	100	
Dover sole	4	1,932	<1	103
n_j = 90	5	9,232	<1	85
	6	135,134	1	25
	7	413,712	2	19
	8	1,560,511	8	11
	9	2,054,728	10	11
	10	2,481,534	13	7
	11	2,889,683	15	6
	12	2,371,421	12	7
	13	1,649,190	8	7
	14	1,309,543	7	9
	15	1,109,327	5	12
	16	944,507	5	10
	17	663,245	3	12
	18	413,662	2	12
	19	313,854	2	16
	20 - 45[b]	635 - 275,363	≤1	15 - 104
	Total	19,851,884	100	

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[a] n_j is the sample size.

[b] Range includes various older ages that individually composed ≤1% of the total landings (in number): 20 ages from 18 to 59 for yellowtail rockfish, 23 ages from 14 to 39 for widow rockfish, 21 ages from 19 to 41 for canary rockfish, 8 ages from 10 to 23 for English sole, and 25 ages from 20 to 45 for Dover sole.

Table 2.6. Age-composition estimates for yellowtail rockfish landings in Oregon, January - December 1991. Landing estimates are in number of fish. Between ($\hat{V}_{BTW}\%$) and within ($\hat{V}_{WTH}\%$) boat-trip components of variation are expressed as percentages of the estimated total variance of the landing estimates. n_j = 35 boat-trip samples.[a]

Age	Landing estimate ($\hat{T}_{.j}$)	Percent of market-category total landings	$\hat{V}_{BTW}\%$	$\hat{V}_{WTH}\%$	CV (%)
5	3,166	<1	97	3	82
6	41,245	3	97	3	24
7	204,751	16	>99	<1	23
8	194,155	15	>99	<1	18
9	121,146	9	>99	1	23
10	176,841	13	99	1	10
11	106,203	8	97	3	9
12	78,627	6	98	2	15
13	81,901	6	99	1	21
14	77,285	6	99	1	14
15	79,947	6	>99	<1	25
16	44,328	3	96	4	15
17	38,624	3	98	2	23
18	15,857	1	98	2	28
19	6,274	<1	99	1	54
20	5,317	<1	97	3	50
21	2,158	<1	98	2	100
22	5,520	<1	97	3	48
23	4,661	<1	97	3	80
24	1,380	<1	98	2	85
25	3,883	<1	97	3	64
26	1,257	<1	98	2	91
28	1,254	<1	98	2	87
29	7,844	1	97	3	52
30	1,271	<1	98	2	63
31	1,086	<1	98	2	99
33	234	<1	98	2	102
35	1,088	<1	98	2	104
39	1,088	<1	98	2	104
41	2,191	<1	98	2	100
42	466	<1	98	2	102
43	1,972	<1	98	2	100
59	918	<1	98	2	103
Total	1,313,938	100			

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[a] Age-composition samples were collected only from the YWT market categories. This sampling approach was used because nearly all of the yellowtail rockfish (>99% in weight) was landed in its own market category in 1991.

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CHAPTER 3

SAMPLING VARIABILITY ASSOCIATED WITH ESTIMATES OF SPECIES AND AGE COMPOSITIONS OF GROUNDFISH LANDINGS IN OREGON (1989-1990)

ABSTRACT

To avoid negative impacts to the marine resource associated with uncontrolled exploitative practices, current Pacific coast fishery management relies on various stock assessment methods to establish quotas and restrict the harvest of selected groundfish species. Assessments are most often based on landing statistics, such as estimates of the species and age compositions of the landings. It is reasonable to assume that the inferences drawn from stock assessments depend on, to some degree, the reliability of the input data on which they are based. An abbreviated version of a multistage sampling approach, which incorporated a single sampling unit at the second stage, was used to document the statistical properties of species- and age-composition estimates for groundfish commercially landed at Oregon ports from 1989 to 1990. Species-composition sampling was conducted on rockfish landings and age-composition sampling was conducted on selected species of rockfish and flatfish.

In general, total landings for four of the six sort groups (market categories) were composed of one or two rockfish species that had landing estimates with very small coefficients of variation (*CVs* <5%). The two remaining market categories included from 6 to 18 various species of rockfish that were generally measured with low precision, with *CVs* greater than 50%. At least two-thirds of the total landings for individual port/quarter strata was composed of precise estimates of species composition (*CVs* <10%). For each year, at least 75% of the total (coastwide) landings of rockfish in Oregon included precise estimates

of individual species. At least three-fourths of the total landings for each of the five species included in the age-composition sampling program consisted of landing estimates of individual ages that had relatively small coefficients of variation (*CVs* ≤25%). The remaining 5 to 25% of the total landings of each species consisted of individual ages that had highly variable landing estimates, with *CVs* greater than 40%.

INTRODUCTION

The estimation of Acceptable Biological Catches (ABCs) is a primary objective of fishery agencies responsible for the management of groundfish stocks commercially harvested from marine waters off of California, Oregon, and Washington. In general, ABCs are catch quotas and reflect biologically based estimates of the amount of fish that may be harvested from the fishery each year without jeopardizing the resource (PFMC 1990). The ABCs are most often implemented for individual species, in some cases species groups, and the coastwide landings of each species or group are monitored. To avoid issues of conflict that accompany premature closure of a fishery, the ABCs usually include boat-trip limits, which can be increased or decreased, to control landing rates and delay achievement of a quota. Fishery management practices that utilize quotas most often rely on some type of sampling program to'track' the total landings of the individual species. For the most part, each state is responsible for developing sampling designs and providing estimates of the amount of fish landed for selected species.

Sampling objectives for estimating the species composition of groundfish landings are currently necessary in Oregon because fish processing facilities, where samples are collected, are not required by law to sort and document the landings by individual species. That is, the commercial enterprises are required to provide landing information, or 'fish tickets,' to the fishery agency according to a legally imposed format; however, these documents are based in large part on economic and business related criteria and the information generally lacks the biological and statistical descriptors necessary for management purposes. Oregon relies on sampling programs to produce estimates of species composition that can be scientifically evaluated.

Stock assessments are an integral component of United States Pacific coast groundfish management. Assessments generally involve some form of analytical search for the exploitation level that in the long run gives the maximum yield of fish in weight or number from the fishery. The derived yields are the basis on which the quotas discussed above are determined. Recent stock assessments most often utilize age-structured models, which require the number of fish caught by each age group as input data; this is the primary purpose for collecting samples of age composition. The uncertainty associated with scientific advice provided to fisheries managers is necessarily related to the variability associated with the input parameters used in assessment models (Pinhorn 1983). For example, the quality of the age-composition data obtained through sampling efforts can be defined by the accuracy and precision associated with the generated landing estimates. Stock assessments that do not consider this variability, quantitatively or qualitatively, provide results that are difficult to interpret in scientific terms and lack the necessary criteria required for statistical inference.

The sampling programs discussed above are often circumscribed by financial and logistical constraints. Additionally, many marine fisheries operate uniquely and require elaborate sampling approaches not commonly employed (e.g., Quinn et al. 1983; Sen 1986). For example, actual landing procedures utilized by fish processing facilities can differ from one port to the next, and statistically appropriate sampling protocols must be flexible enough to address the nuances that can exist between landing sites. To address these issues, Oregon adopted a modified version of a multistage sampling design developed for commercially landed rockfish in California (Sen 1986). The modified design required selecting only a single sampling unit at the second stage. This sample selection approach was adopted because it is flexible and capable of being implemented at most processing facilities, even when dockside operations require sampling teams to collect information in less than ideal conditions. For example, the design is particularly useful when collecting samples of age composition because the port biologist is able to obtain samples of fish quickly (including various hard parts, such as otoliths and opercles) without impeding the rapid and somewhat hectic unloading practices common to many fish processing facilities.

All commercial fishery sampling programs must consider these unique and restrictive aspects of the sample sites, which often result in estimates that reflect some level of compromise between accuracy and precision (Gulland 1955, 1966; Tomlinson 1971; Bazigos 1974). The sampling design presented here utilizes estimators that provide statistically valid estimates of means and totals; however, the estimated variances are inherently biased because the variation at the second stage of the design was ignored. The bias associated with the variance estimates was *assumed* to be inconsequential for management purposes. This assumption was primarily based on research conducted on the rockfish fishery of California, which showed that most of the sampling error associated with groundfish landings was due to variability at the first stage of a two-stage sampling plan (Parker and MacCall 1990).

This chapter describes the sampling design used for estimating species and age compositions of the commercial landings in Oregon from 1989 to 1990. Statistical formulae appropriate to the data collection protocols associated with the sampling design are presented, and selected species- and age-composition estimates and their measures of dispersion are documented. The objective of this research was to determine the magnitudes of variability associated with sample data used in commercial fishery management. The results from these analyses serve as objective criteria for determining effective tradeoffs in sample allocation between different market categories and strata. This type of information is necessary to qualify the advice given to managers and researchers involved in determining the status of a particular stock. Variance estimates of species composition presented in this chapter represent the first documentation of the levels of uncertainty associated with commercial landings in Oregon. Additionally, the measures of error associated with estimates of age composition are the only statistics currently available to evaluate critically the reliability of the sample data used in Pacific coast stock assessment research. Finally, based on results generated from the complete two-stage sampling design presented in Chapter 2, I discuss the levels of risk associated with inferences and interpretations suggested by the landing statistics generated from the abbreviated multistage design.

METHODS

The general properties of the sampling design discussed here, as well as definitions and descriptions of market categories, landings, statistical populations, measures of variation, sampling objectives, and field sampling procedures have been previously presented in Chapter 2 (see Methods). Sampling methods that are unique to the design presented here are discussed below for the species- and age-composition sampling programs.

Species-composition Sampling Program

Since 1989, Oregon has primarily employed a modified, two-stage random sampling design to collect sample data of species composition (Sen 1986). This design incorporates more flexible and less rigorous sample selection protocols at the second stage of sampling than required in the multistage approach used to collect samples of species composition presented in Chapter 2 (see Methods, Species-composition Sampling Program). The sampling design required selecting only a single basket of fish for each market category sampled within a boat trip; all other sampling procedures were similar to those discussed previously in Chapter 2.

It is important to note that although replicate baskets were actually selected from each market category, the data from the basket samples were mistakenly combined and recorded as single baskets of fish that were unequal in size (i.e., in weight) across the boat-trip samples—the size depended on how many baskets were selected and summed together. From the standpoint of distribution-free sample estimation theory, the variance component at the second stage of sampling was indeterminable because the replicate samples necessary to calculate this term were absent. The primary weakness of this sampling design was that it produced variance measures that were biased (i.e., underestimates of the expected value of the variance parameters), the extent of which depended on the magnitude of variation that existed at the second stage of sampling.

Age-composition Sampling Program

Sampling techniques used to collect age-composition data from 1989 through 1990 were similar to the field methods utilized for age-composition sampling presented in Chapter 2 (see Methods, Age-composition Sampling Program and Estimation Procedures). However, the design employed from 1989 to 1990 required selecting approximately 50 fish (recorded as a single basket weight) from each sampled market category within a boat trip, rather than taking replicate samples at the second stage as described in Chapter 2; all other sampling protocols were similar between the two designs.

Estimation Procedures

The following formulae for mean and total landing estimates and their variances follow Sen (1986), see section Estimation Based on Categories as Domains of Study (formulae for second-stage sampling units of unequal size, pages 412-413). These formulae are appropriate for two-stage sampling designs in which: (1) the secondary sampling units vary (i.e., are unequal or not fixed) in size across the primary sampling units; or, (2) a single secondary sampling unit is selected, which is constant (i.e., is equal or fixed) or varys in size across the primary sampling units. Landing statistics presented here are based on a sampling design similar to (2) above, where a single basket of fish was selected within each sampled market category of a boat trip and the basket sizes (weights) varied across trips. I use a coefficient of variation (*CV*) as the measure of dispersion associated with a landing estimate. The *CV* was calculated as: [(standard error of the landing estimate / total landing estimate) • 100]; this statistic is also referred to as a relative standard error (Som 1973) and a coefficient of variation of the estimate (Cochran 1977).

Notation and Formulae

Notation presented in Chapter 2 is applicable to sampling estimators (3.1 - 3.10) presented below. The estimators are based on straightforward ratio estimation techniques (e.g., Sukhatme and Sukhatme 1970; Cochran 1977; Scheaffer et al. 1990), which have been applied to commercial fishery data. I present formulae and discussion that pertain to analyses of species composition; however, the estimation procedures can be applied similarly to samples of age composition after landing weights have been converted to numbers, see Additional Notation and Formulae: Age-composition Sampling Program, equations (3.11 - 3.14).

The estimated mean basket weight for market category j of boat trip i is calculated as,

$$\bar{w}_{ij.} = \frac{\sum_{k=1}^{m_{ij}} w_{ijk}}{m_{ij}} , \qquad (3.1)$$

and the estimated mean weight of species y per basket in market category j of boat trip i is,

$$\bar{y}_{ij.} = \frac{\sum_{k=1}^{m_{ij}} y_{ijk}}{m_{ij}} . \qquad (3.2)$$

Note that landing estimates for fishery data collected in 1989 and 1990 were based on single secondary sampling units of unequal size, $m_{ij} = 1$; thus, for each sampled market category within a boat trip, $\bar{y}_{ij.}$ was simply the weight of species y in the single basket of fish selected, $\bar{w}_{ij.}$.

The ratio estimator for the percent composition of species *y* in market category *j* of boat trip *i* is,

$$\hat{R}_{ij} = \frac{\bar{y}_{ij.}}{\bar{w}_{ij.}} , \tag{3.3}$$

and the ratio estimator for the percent composition of species *y* in market category *j* across all boat trips is,

$$\hat{R}_{.j} = \frac{\sum_{i=1}^{n_j} \hat{R}_{ij} W_{ij}}{\sum_{i=1}^{n_j} W_{ij}} . \tag{3.4}$$

Equation (3.4) is a weighted estimator, where samples from boat trips with market-category landings that are large in size are given more weight in estimating $\hat{R}_{.j}$, than boat trips with relatively small landing sizes.

The ratio estimator for the total landings, in weight, of species *y* in market category *j* is,

$$\hat{Y}_{R.j} = \frac{\sum_{i=1}^{n_j} W_{ij} \hat{R}_{ij}}{\sum_{i=1}^{n_j} W_{ij}} W_{.j} = \hat{R}_{.j} W_{.j} , \tag{3.5}$$

and the estimator for the total landings, in weight, of species *y* across all market categories is,

$$\hat{Y}_{R..} = \sum_{j=1}^{L} \hat{Y}_{R.j} . \tag{3.6}$$

Given similar sampling protocols are used to select baskets from each market category j, the estimated variance of $\hat{R}_{.j}$ is,

$$\hat{V}(\hat{R}_{.j}) \cong \left(\frac{N_j - n_j}{N_j n_j (n_j - 1)}\right) \sum_{i=1}^{n_j} \left(\frac{W_{ij}}{\hat{\bar{W}}_{.j}}\right)^2 (\hat{R}_{ij} - \hat{R}_{.j})^2 \text{, where}$$

$$\hat{\bar{W}}_{.j} = \frac{\sum_{i=1}^{n_j} W_{ij}}{n_j} . \tag{3.7}$$

The estimator $\hat{V}(\hat{R}_{.j})$ documents the variance associated with landing estimates of species y in market category j between boat trips, or primary sampling units, and disregards the variation at the second stage of sampling. That is, because only a single basket of fish was selected within a sampled market category, $m_{ij} = 1$, it was not possible to measure the variation at the second stage of the design using multistage sampling estimators. Thus, the variation at the second stage of sampling was assumed to be zero—the validity of this assumption is addressed in the Discussion, as well as in Chapter 2. Additionally, the estimate of the population mean landing weight for market category j across all boat trips, $\hat{\bar{W}}_{.j}$, becomes a poor statistic when: (1) there is a large amount of variation among the total weights of market category j across the entire population of boat trips, the W_{ij}, and (2) very few boat trips are sampled (n_j is small); therefore, the variances themselves are subject to additional bias when these situations occur. When it is possible to ascertain population parameters, usually after the fishing season, a more appropriate estimate of the population mean weight of market category j per boat trip would be $W_{.j} / N_j$.

Estimated variances for the total landing estimators are,

$$\hat{V}(\hat{Y}_{R.j}) \cong (W_{.j})^2 \left(\frac{N_j - n_j}{N_j n_j (n_j - 1)} \right) \sum_{i=1}^{n_j} \left(\frac{W_{.j}}{\hat{\bar{W}}_{.j}} \right)^2 (\hat{R}_{ij} - \hat{R}_{.j})^2 = (W_{.j})^2 \hat{V}(\hat{R}_{.j}) \text{ ,} \quad (3.8)$$

and

$$\hat{V}(\hat{Y}_{R..}) \cong \sum_{j=1}^{L} \hat{V}(\hat{Y}_{R.j}) + 2 \sum_{a<b} \sum \text{COV}(\hat{Y}_{R.a}, \hat{Y}_{R.b}) \text{ .} \quad (3.9)$$

If only one market category is sampled per boat trip or the estimates of species composition from two or more market categories sampled from the same boat trip are assumed to be independent (see Chapter 2, equation (2.10) for further discussion), then equation (3.9) simplifies to,

$$\hat{V}(\hat{Y}_{R..}) \cong \sum_{j=1}^{L} \hat{V}(\hat{Y}_{R.j}) \text{ .} \quad (3.10)$$

Additional Notation and Formulae: Age-composition Sampling Program

The estimators used in analyses of species composition presented above are also applicable to age-composition sample data collected from 1989 to 1990. However, these age-composition data required preliminary analyses before equations (3.1 - 3.10) could be applied. That is, estimates of age composition are most often presented as the number of fish landed within age groups (cohorts or classes), rather than the weight of fish landed. Empirical procedures used to convert landing weights to numbers are as follows. To convert landing weights to numbers of fish, let

Number of fish:

X_{ij} ≡ number of fish landed in market category j of boat trip i,

$X_{.j}$ ≡ total number of fish landed in market category j across all boat trips,

x_{ijk} ≡ number of fish in basket k sampled from market category j of boat trip i.

Average weight of an individual fish:

A_{ij} ≡ average weight of an individual fish in market category j of boat trip i,

$A_{.j}$ ≡ average weight of an individual fish in market category j across all boat trips,

The estimator for the average weight of an individual fish in market category j of boat trip i is,

$$\hat{A}_{ij} = \frac{\sum_{k=1}^{m_{ij}} w_{ijk}}{\sum_{k=1}^{m_{ij}} x_{ijk}} , \tag{3.11}$$

and the estimator for the total number of fish in market category j of boat trip i is,

$$\hat{X}_{ij} = \frac{W_{ij}}{\hat{A}_{ij}} . \tag{3.12}$$

Based on equations (3.11) and (3.12), the estimator for the average weight of an individual fish in market category j across all boat trips is,

$$\hat{A}_{.j} = \frac{\sum_{i=1}^{n_j} \hat{X}_{ij} \hat{A}_{ij}}{\sum_{i=1}^{n_j} \hat{X}_{ij}} = \frac{\sum_{i=1}^{n_j} W_{ij}}{\sum_{i=1}^{n_j} \hat{X}_{ij}} , \tag{3.13}$$

and the total weight of fish landed for market category j, $W_{.j}$, is converted into an estimate for the total number of fish landed as follows,

$$\hat{X}_{.j} = \frac{W_{.j}}{\hat{A}_{.j}} . \tag{3.14}$$

The variation associated with the estimators above (equations 3.11 - 3.14) was not accounted for in the analyses of age composition presented here, which in effect, increases the amount of uncertainty (bias) associated with the derived estimates from these sampling methods. Finally, the following modifications to the notation presented in Chapter 2 and formulae presented above (equations 3.1 - 3.10) are necessary to calculate estimates of age composition that are based on landing numbers, rather than weights. For a particular species: (1) y_{ijk} is recorded as the number of age y fish in basket k sampled from market category j of boat trip i; and, (2) x_{ijk}, $\hat{X}_{ij}$, $\hat{\hat{X}}_{.j}$, and $\hat{X}_{.j}$ are substituted for w_{ijk}, W_{ij}, $\hat{\hat{W}}_{.j}$, and $W_{.j}$, respectively.

RESULTS

Results are presented separately for the species- and age-composition sampling programs. Estimates of species composition are presented as weight (in kg) of fish landed and estimates of age composition are presented as number of fish landed.

Species-composition Sampling Program

Species-composition data collected from January 1989 through December 1990 were incorporated into the analyses presented in this chapter. Landing statistics were very consistent across the various strata analyzed. The two-year database used in these analyses generated numerous and lengthy tables associated with the individual strata; therefore, for purposes of brevity in presentation, I selected a typical stratum to illustrate the statistical properties of the rockfish landings, namely Astoria/2nd quarter 1990. Additional estimates of species composition of rockfish landings in Oregon from 1989 to 1990 are presented in Appendix B (Tables B.1 - B.4).

In general, the large rockfish complex (LRC) and small rockfish complex (SRC) market categories were composed of many species that had landing estimates that were highly variable, with *CVs* that ranged from 20 to over 100%, the majority of which were greater than 30% (Table 3.1). For example, for the Astoria/2nd quarter 1990 stratum, canary rockfish, which composed nearly one-half of the LRC market category, was the only species landed in either of the complex market categories that was measured with even moderately high precision, with a $CV = 20\%$. For most strata, the LRC and SRC market categories included one or two dominant species (i.e., represented large proportions of the market-category total landings) that had landing estimates that were less variable than the remaining species, with *CVs* that ranged from 15 to 30%.

The thornyhead (TYH) market category most often contained only shortspine and/or longspine thornyhead (Table 3.1); however, in several cases (strata) this market category also contained other miscellaneous rockfish. One of the thornyhead species always composed at least one-half of the total landings of the TYH market category and these landing estimates were usually very precise, with *CVs* <15%. The precision of the landing estimates for the thornyhead species was inconsistent in cases where they did not compose at least one-half of the total landings, with *CVs* that ranged from 2 to 75%. In roughly one-third of the strata, the TYH market category was composed entirely of shortspine or longspine thornyhead (e.g., the Astoria/2^{nd} quarter 1990 stratum, Table 3.1). The miscellaneous species, which together never composed greater than 5% of the total landings of the TYH market category, had landing estimates that were highly variable, with *CVs* >100%.

The Pacific ocean perch (POP), yellowtail rockfish (YWT), and widow rockfish (WDW) market categories consisted primarily of their own species, namely Pacific ocean perch, yellowtail rockfish, and widow rockfish, for the three market categories, respectively (Table 3.1). The landings associated with the above species were estimated with very high precision, with *CVs* always less than 10% and usually less than 5%. The other rockfish landed in these three market categories had estimates that were highly variable, with *CVs* generally greater than 50%.

Landing estimates of species composition summed over market categories were also consistent across the various strata analyzed. In general, for each stratum, at least two-thirds of the total landings of rockfish was composed of from one to five species that had very precise landing estimates, with *CVs* <10% (Table 3.2). For the most part, this precise landing information consisted of species landed in their own market categories, namely yellowtail rockfish, widow rockfish, Pacific ocean perch, and shortspine and longspine thornyhead. For each stratum, the remaining one-third of the total landings was measured with low precision and included various species of rockfish that were primarily landed in the LRC and SRC market categories; the *CVs* associated with these landing estimates were generally greater than 30%.

Age-composition Sampling Program

Age-composition data collected from January 1989 through December 1990 were incorporated into analyses presented in this chapter. Estimates of age composition and their errors are presented in a summary table for each year.

Landing statistics were very consistent for all five species incorporated into analyses of age composition for 1989 to 1990 groundfish landings. In general, estimates of age composition were more variable than estimates of species composition. That is, the total landings of each species included very few estimates of individual ages that had *CVs* <10%. The majority of the total landings of each species included estimates of age composition that had *CVs* <25%. It is important to note, there is no generally agreed upon *CV* value or range that defines a 'precise' landing estimate, rather, a suitable measure of precision reflects the level of uncertainty a fishery manager is willing to accept regarding the statistic of interest.

In general, the age composition for each species consisted of a relatively small range of consecutive ages that individually composed ≥5% of the total landings and these estimates were relatively precise, with *CVs* <25% (Tables 3.3 and 3.4). These age ranges contributed approximately 75 to 95% to the total landings of each species, whereas the remaining 5 to 25% of each age composition consisted of estimates of individual ages that: (1) did not makeup large portions of the total landings; and, (2) were highly variable, with *CVs* usually greater than 40%.

For example, roughly 90% of the total number of yellowtail rockfish landed in 1990 at Oregon ports consisted of fish that ranged in age from age 6 to 16 (Table 3.4). Each of the estimates for ages 6 to 16 contributed at least 5% to the total landings, and with the exception of the landing estimate for age-6 fish (*CV* = 33%), was relatively precise, with *CVs* that ranged from 10 to 25%. The remaining approximately 10% of the age composition for yellowtail rockfish in 1990 included estimates for ages that individually composed ≤3% of the total landings and had *CVs* that ranged from 26 to 103%, the majority of which were greater than 40%.

DISCUSSION

Topics of discussion are presented separately for the species- and age-composition sampling programs.

Species-composition Sampling Program

The majority of the rockfish landings from 1989 to 1990 were measured with very high precision (*CVs* <10%). However, a substantial portion of the total landings, from 25 to 33% depending on the detail of information, consisted of landing information that was moderately to highly variable, with *CVs* that ranged from 30 to over 100%.

Precise landing information allows fishery managers to 'track' the accumulated catch of individual species with more confidence (certainty) than attempts to monitor the landings based on variable estimates. For example, the *CV* of 1% associated with the yellowtail rockfish landing estimate of 859,962 lb (Table 3.2) translates to a 75% confidence interval (*CI*) approximately equal to 842,763 to 877,161 lb—the statistical properties and practical interpretation of the 75% *CI* are discussed in Chapter 2, Discussion. The landing estimate of 406,544 lb for canary rockfish has a *CV* = 20%, which produces a 75% *CI* equal to 243,926 to 569,162 lb. The *CI* associated with the landing estimate of canary rockfish is considerably wider and thus, less informative than the *CI* for landings of yellowtail rockfish. That is, although the level of certainty (or confidence) associated with the *CIs* of these two species is the same, the actual landing estimate for canary rockfish is difficult to interpret definitively. The *CI* can be practically interpreted as an interval estimate of the true population parameter, and the interval associated with the landing estimate of canary rockfish reflects a range of possible values that is not very useful to a fishery manager.

The variance estimates generated from this sampling design are likely underestimates of the true population variance parameters, given the selection protocols at the second stage of sampling. However, the exact behavior of the statistical bias cannot be predicted a priori and appears to be 'market-category specific.' That is, the bias is much more problematic in situations where the magnitude of variability between baskets of fish within a sampled market category is substantial. Results presented in Chapter 2 indicate that this bias is potentially significant for variance measures associated with several components of species-composition information.

Research conducted on the California rockfish fishery demonstrated that the variance estimates generated from a multistage design were primarily due to sampling error at the first stage of sampling, *between* boat trips (Parker and MacCall 1990). The results from research conducted on the fishery of California are not necessarily relevant to the fishery in Oregon, given that the characteristics of the landings often differ across states, as well as within a state, due to: (1) differences in the spatial and temporal distributions of the exploited species inhabiting the coastal marine waters of the Pacific coast; (2) differences in fishery operations across ports and states; and, (3) dynamic management policies that are based on updated quotas.

The variance estimates of species composition for rockfish landings from 1989 to 1990 are baseline statistics that should be interpreted cautiously, given the tenuous assumption that the magnitude of second-stage variation is insignificant and does not warrant sampling attention. Given that estimates of species composition of the landings are primary databases utilized in fishery management, it is imperative that evaluations be conducted regarding the 'quality' of this information before harvest strategies are implemented. The results presented here are intended to provide fishery managers information to assess the reliability of the landing estimates, which will allow management approaches to be adopted that reflect the levels of uncertainty associated with these sample data.

Age-composition Sampling Program

Studies aimed at determining the impact of variable sample data on stock assessments have received little attention in fisheries science (Pope and Gray 1983), which complicates interpretations regarding management implications suggested in the statistics presented here. That is, the total landings of each species were primarily composed of estimates of age composition that had *CVs* <25%; however, the influence that this variability has on modelling procedures and subsequent management advice is difficult to ascertain given the empirical complexities associated with most stock assessment techniques.

Regardless of the intricacies, as well as the inadequacies of stock assessment methods (Gulland 1988; Megrey and Wespestad 1988; Megrey 1989), it seems reasonable that precise input data are more likely to generate precise advice (e.g., recommended quota levels) than variable input data (Pope 1983b; Walters 1986; Stanley 1992). At the very least, documentation of the variability associated with the actual age-composition data (i.e., input data) allows fishery managers to assess intuitively the quality of the results (i.e., output data) generated from stock assessment models. The results presented in this chapter should be interpreted as conservative measures of the variability associated with estimates of age composition for five groundfish species landed at Oregon ports in 1989 and 1990.

Additionally, the landing statistics presented here are critical to developing and revising sampling programs to meet the needs of management. For example, sampling should be planned to minimize variance on estimates of critical parameters and provide information that can be used to examine important assumptions used in stock assessment models—research presented in Chapter 4 addresses these issues.

Results from analyses of age composition generated from the complete two-stage sampling design (Chapter 2) indicate that the amount of variability at the second stage of sampling was consistently small, which indicates the bias associated with these variance measures is not likely to influence any practical interpretation of the estimates. In Chapter 2, I discuss the relevancy and implications of negligible second-stage variation to fishery sampling programs administered for purposes of age-composition determination.

In general, the drawbacks of the sampling approach used to generate estimates of age composition and their errors presented here are similar to those discussed above for the species-composition sampling program. Further caution should be used when evaluating the estimates of age composition for 1989-90 sample data because: (1) an additional source of bias is associated with the estimates, see Additional Notation and Formulae: Age-composition Sampling Program; and more importantly, (2) as discussed above, the stochastic properties of the sample data are not easily accounted for in stock assessment models, which results in management advice that is difficult to evaluate critically.

Table 3.1. Species-composition estimates by market category for the Astoria/2nd quarter 1990 stratum. Landing estimates are in pounds of fish.

Market category [a]	Rockfish species	Landing estimate ($\hat{T}_{R.j}$)	Percent of market-category total landings ($\hat{R}_{.j}$)	*CV* (%)
LRC n_j [b] = 22	Canary	396,510	46	20
	Silvergrey	116,141	13	37
	Puget Sound	87,312	10	37
	Darkblotched	82,498	10	66
	Bocaccio	70,682	8	52
	Yelloweye	16,013	2	43
	Pacific ocean perch	15,260	2	32
	Redstripe	14,251	2	50
	Rougheye	13,564	2	34
	Sharpchin	10,697	1	35
	Splitnose	9,963	1	56
	Yellowtail	9,721	1	58
	Yellowmouth	7,529	1	45
	Greenstriped	5,734	<1	74
	Aurora	2,640	<1	56
	Redbanded	2,625	<1	73
	Widow	1,701	<1	60
	Rosethorn	900	<1	47
	Shortspine thornyhead	885	<1	72
	Stripetail	103	<1	100
	Blackgill	69	<1	100
	Subtotal	864,798	100	
SRC n_j = 4	Darkblotched	36,896	46	40
	Redstripe	12,720	16	72
	Pacific ocean perch	7,014	9	37
	Splitnose	6,644	8	66
	Sharpchin	6,448	8	64
	Aurora	4,913	6	33
	Yellowmouth	2,080	2	57
	Greenstriped	1,622	2	64
	Canary	1,398	2	87
	Rosethorn	404	<1	72
	Widow	145	<1	94
	Redbanded	110	<1	102
	Subtotal	80,394	100	
TYH n_j = 5	Shortspine thornyhead	287,349	100	0
	Subtotal	287,349	100	

Table 3.1. (*Concluded*)

Market category [a]	Rockfish species	Landing estimate ($\hat{T}_{R.j}$)	Percent of market-category total landings ($\hat{R}_{.j}$)	*CV* (%)
POP	Pacific ocean perch	182,459	97	1
n_j [b] = 12	Darkblotched	1,592	1	60
	Splitnose	1,498	1	50
	Rougheye	675	<1	91
	Yellowmouth	458	<1	91
	Sharpchin	327	<1	98
	Shortspine thornyhead	92	<1	94
	Subtotal	187,101	100	
YWT	Yellowtail	843,590	97	1
n_j = 19	Widow	10,739	1	46
	Canary	8,636	1	82
	Silvergrey	4,373	<1	94
	Greenstriped	503	<1	72
	Darkblotched	472	<1	99
	Sharpchin	325	<1	77
	Redstripe	258	<1	95
	Subtotal	868,896	100	
WDW	Widow	763,459	99	1
n_j = 19	Yellowtail	6,651	<1	59
	Redstripe	1,466	<1	53
	Sharpchin	48	<1	97
	Subtotal	771,624	100	
	Total	3,060,162		

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[a] Market-category acronyms are as follows: (1) LRC is large rockfish complex, (2) SRC is small rockfish complex, (3) POP is Pacific ocean perch, (4) WDW is widow rockfish, (5) YWT is yellowtail rockfish, and (6) TYH is thornyhead.

[b] n_j is the sample size.

Table 3.2. Species-composition estimates for the Astoria/2^{nd} quarter 1990 stratum. Landing estimates are in pounds of fish.

Rockfish species	Landing estimate ($\hat{T}_{R..}$)	Percent of stratum total landings	*CV* (%)
Yellowtail	859,962	28	1
Widow	776,044	25	1
Canary	406,544	13	20
Shortspine thornyhead	288,326	9	1
Pacific ocean perch	204,733	7	3
Darkblotched	121,458	4	47
Silvergrey	120,514	4	36
Puget Sound	87,312	3	37
Bocaccio	70,682	2	52
Redstripe	28,695	1	41
Splitnose	18,105	1	39
Sharpchin	17,845	1	31
Yelloweye	16,013	1	43
Rougheye	14,239	<1	32
Yellowmouth	10,067	<1	36
Greenstriped	7,859	<1	56
Aurora	7,553	<1	29
Redbanded	2,735	<1	70
Rosethorn	1,304	<1	40
Stripetail	103	<1	100
Blackgill	69	<1	100
Total	3,060,162	100	

Table 3.3. Age-composition summaries for groundfish landings in Oregon, January - December 1989. Landing estimates are in number of fish.

Species	Age	Landing estimate ($\hat{T}_{R.j}$)	Percent of total landings	*CV* (%)
Yellowtail rockfish	5	15,874	1	38
n_j [a] = 41	6	58,245	5	31
	7	42,275	3	23
	8	118,812	9	25
	9	110,791	9	12
	10	93,960	7	12
	11	123,968	9	10
	12	135,600	11	8
	13	156,871	12	10
	14	108,836	8	17
	15	100,882	8	16
	16	63,512	5	33
	17	33,625	3	41
	18 - 59 [b]	34 - 16,799	≤1	26 - 102
	Total	1,285,352	100	
Widow rockfish	4	90,651	1	40
n_j = 111	5	399,169	5	13
	6	718,504	9	10
	7	1,516,842	19	6
	8	2,950,237	37	4
	9	1,215,656	15	7
	10	388,819	5	12
	11	239,501	3	15
	12 - 43 [b]	80 - 93,176	≤1	21 - 96
	Total	7,983,381	100	
Canary rockfish	4	77	<1	106
n_j = 22	5	236	<1	105
	6	5,434	1	34
	7	17,486	3	35
	8	31,265	5	32
	9	54,714	8	18
	10	92,726	14	12
	11	83,649	13	13
	12	61,279	9	16
	13	50,224	7	9
	14	40,320	6	15
	15	28,909	4	13
	16	21,525	3	26
	17	11,686	2	19

Table 3.3. (*Concluded*)

Species	Age	Landing estimate ($\hat{T}_{R.j}$)	Percent of total landings	CV (%)
	18	16,269	2	30
	19	14,869	2	24
	20	23,248	3	42
	21 - 24[b]	4,256 - 8,466	≤1	45 - 65
	25	84,442	13	19
	Total	666,684	100	
English sole n_j[a] = 24	2	146	<1	105
	3	14,282	1	46
	4	182,723	8	17
	5	649,232	28	8
	6	697,046	30	6
	7	294,461	13	9
	8	166,595	7	15
	9	129,681	6	20
	10	61,185	3	34
	11	44,660	2	44
	12 - 16[b]	2,598 - 32,611	≤1	48 - 100
	Total	2,296,903	100	
Dover sole n_j = 60	5	79,750	<1	52
	6	238,536	1	41
	7	454,302	2	22
	8	1,247,753	6	15
	9	1,963,398	10	10
	10	2,325,226	12	10
	11	2,052,398	10	7
	12	2,211,270	11	7
	13	1,893,412	9	7
	14	1,572,128	8	8
	15	1,319,213	7	13
	16	940,304	5	12
	17	791,348	4	12
	18	507,163	3	14
	19	414,069	2	24
	20	284,212	1	25
	21	343,074	2	21
	22 - 49[b]	7,755 - 262,442	≤1	23 - 99
	Total	20,027,833	100	

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[a] n_j is the sample size.

[b] Range includes various older ages that individually composed ≤1% of the total landings (in number): 22 ages from 18 to 51 for yellowtail rockfish, 25 ages from 12 to 43 for widow rockfish, 4 ages from 21 to 24 for canary rockfish, 5 ages from 12 to 16 for English sole, and 21 ages from 22 to 49 for Dover sole.

Table 3.4. Age-composition summaries for groundfish landings in Oregon, January - December 1990. Landing estimates are in number of fish.

Species	Age	Landing estimate ($\hat{Y}_{R.j}$)	Percent of total landings	CV (%)
Yellowtail rockfish	1	436	<1	101
n_j [a] = 35	4	236	<1	101
	5	23,759	2	45
	6	140,419	11	33
	7	132,329	10	18
	8	81,400	6	18
	9	135,648	10	15
	10	142,835	11	10
	11	96,412	7	15
	12	101,234	8	14
	13	89,401	7	18
	14	102,838	8	25
	15	74,107	6	13
	16	62,956	5	22
	17	37,099	3	26
	18	21,001	2	32
	19 - 46 [b]	43 - 8,852	≤1	28 - 103
	Total	1,317,049	100	
Widow rockfish	4	23,950	<1	44
n_j = 120	5	366,502	6	24
	6	403,290	7	12
	7	589,522	10	7
	8	935,597	16	6
	9	1,522,237	27	5
	10	907,536	16	7
	11	382,785	7	10
	12	220,882	4	12
	13	107,295	2	15
	14 - 38 [b]	837 - 50,203	≤1	25 - 101
	Total	5,698,726	100	
Canary rockfish	5	497	<1	96
n_j = 10	6	5,400	1	46
	7	24,311	5	13
	8	26,132	5	13
	9	48,236	9	11
	10	49,471	10	24
	11	79,570	15	5
	12	74,952	14	15
	13	45,056	9	18

Table 3.4. (*Continued*)

Species	Age	Landing estimate ($\hat{T}_{R.j}$)	Percent of total landings	*CV* (%)
	14	45,546	9	39
	15	19,631	4	41
	16	16,476	3	15
	17	18,321	4	21
	18	9,148	2	63
	19	8,694	2	60
	20	9,307	2	34
	21 - 55[b]	4,256 - 8,466	≤1	54 - 113
	Total	518,717	100	
English sole n_j[a] = 21	1	5,954	<1	90
	3	101,650	6	42
	4	210,029	14	10
	5	596,244	38	10
	6	383,415	25	9
	7	107,822	7	9
	8	57,060	4	26
	9	43,352	3	22
	10 - 17[b]	373 - 21,847	≤1	34 - 109
	Total	1,555,148	100	
Dover sole n_j = 63	5	19,972	<1	61
	6	213,597	1	39
	7	335,379	2	28
	8	491,080	3	25
	9	875,221	5	16
	10	1,094,929	6	13
	11	1,264,025	7	9
	12	1,683,401	10	8
	13	1,806,233	11	11
	14	1,790,534	11	11
	15	1,323,963	8	10
	16	1,199,555	7	8
	17	1,121,167	7	16
	18	719,098	4	15
	19	562,226	3	14
	20	600,631	3	15

Table 3.4. (*Concluded*)

Species	Age	Landing estimate ($\hat{T}_{R.j}$)	Percent of total landings	*CV* (%)
	21	301,634	2	15
	22	301,627	2	22
	23 - 49[b]	459 - 219,916	≤1	26 - 101
	Total	19,851,884	100	

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[a] n_j is the sample size.

[b] Range includes various older ages that individually composed ≤1% of the total landings (in number): 22 ages from 19 to 46 for yellowtail rockfish, 21 ages from 14 to 38 for widow rockfish, 17 ages from 21 to 55 for canary rockfish, 8 ages from 10 to 17 for English sole, and 23 ages from 23 to 49 for Dover sole.

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CHAPTER 4

EVALUATION OF ASSUMED ERROR STRUCTURE IN STOCK ASSESSMENT MODELS THAT USE SAMPLE ESTIMATES OF AGE COMPOSITION

ABSTRACT

The sampling error associated with estimates of age composition for five groundfish species commercially landed at Oregon ports is used to examine critically the ability of age-structured stock assessment models to describe adequately the stochastic properties of actual catch-at-age data. Specifically, estimated coefficients of variation associated with samples of catch-at-age are presented graphically to evaluate a theoretical consideration involved in stock assessment models widely used in marine fishery management. Results presented here indicate that a multinomial probability error structure, included in models that are based on maximum likelihood estimation, more closely follows the variability associated with the sampled landing data than does a lognormal error structure used in models based on least squares estimation. Residual analyses are used to determine the specific multinomial curve that best describes the variability associated with the actual sample estimates of age composition and implications for stock assessment modelling are discussed.

INTRODUCTION

In recent years, stock assessment models have gained widespread application in fisheries management. In particular, several age-structured assessment methods have become the primary tools used to derive estimates of fishery parameters, such as fish population abundance and exploitation rates, in many fisheries throughout the world (Megrey 1989).

The motivation behind these assessment methods is that a time series of catch-at-age data for a fishery (i.e., estimates of age composition of the landings for a particular stock) can be analyzed in mathematical terms and used to model certain biological processes of fish populations, such as growth, mortality, and reproduction. The extent to which these models can describe or predict the inherent stochastic properties of an animal population is based largely on the validity and reliability associated with their parameters and assumptions (Pielou 1977; Gulland 1983).

It is generally agreed that estimates of catch-at-age alone are insufficient to determine reliably the status of exploited fish stocks (Doubleday 1976; Pope 1977; Megrey and Wespestad 1988; Quinn and Collie 1990). The types and function of auxiliary data in fishery models need to be examined rigorously to safeguard against inappropriate application in management situations. In particular, it is critical that important model assumptions be reviewed and tested to ensure that generated results are interpreted appropriately (Gudmundsson 1986; Edwards and Megrey 1989; Schnute 1989; Sampson 1993).

To date, one of the most important advances in model development has been the inclusion of an error structure to address the variability associated with the: (1) separate biological processes that influence fish population abundance, such as reproduction and mortality; and, (2) input data on which the models are based, namely the sample estimates of catch-at-age (see Megrey (1989) for an extensive review of age-structured stock assessment models). The age-structured assessment models that accommodate stochastic data can be broadly classified into two groups based on the statistical estimation technique that is used (Kimura 1989): (1) the method of least squares (e.g., Doubleday 1976; Pope and Shepherd 1982; Deriso et al. 1985; Deriso et al. 1989; Kimura 1989); or, (2) the method of maximum likelihood based on multinomial distribution probabilities (e.g., Fournier and

Archibald 1982; Dupont 1983; and Methot 1989, 1990). Note that the least squares and maximum likelihood methods generate equivalent solutions if the error terms are assumed to be distributed as normal random variables (Bain and Engelhardt 1987). Additionally, it is important to note, that although the two groups of models above are most often defined by distinct error structures, each estimation method (nonlinear least squares and multinomial maximum likelihood) is capable of fitting lognormally and multinomially distributed catch-at-age data (Kimura 1990).

An important theoretical consideration when choosing an appropriate stock assessment model involves defining the correct sampling distribution for estimates of age composition (Kimura 1990). The focus of the work described here is the assumed error structure for age composition data relied upon in the different models, which is one criterion that can be used to differentiate the two groups of models discussed above. That is, the objective of this research does not directly involve a critical examination of the methods of estimation utilized by the different models.

The suite of models that are based on least squares estimation generally assume that observation errors in catch-at-age data are lognormally distributed and the models use $\log_e$ transformed estimates of catch-at-age. The least squares estimators assume constant variance of the log transformed estimates of catch-at-age, which dictates that the coefficients of variation (*CVs*) associated with the untransformed catch-at-age estimates be approximately equal (Kimura 1989, 1990; Methot 1990).

In the models that use maximum likelihood estimation, the error structure for catch-at-age data is based on multinomial probabilities, which implies that the *CVs* associated with the estimates of proportion-at-age are distributed in a multinomial fashion (Methot 1990). That is, the *CVs* are inversely related to the true proportions-at-age, where the size of the

CV decreases steadily as the size of the proportion increases. The population variance of a proportion derived from a multinomial distribution is treated as a binomially defined parameter and calculated as, $V(P) \cong [P\,(1 - P) / N]$, where P is the population proportion and N is the number of units in the population. The *CV* of P is calculated as, $[(\sqrt{V(P)}/P) \cdot 100]$. In probability theory, N can be practically interpreted as an indicator term that defines a particular error structure (curve) from an infinite number of possible curves associated with a distribution parameter. In stock assessment models, N is replaced by a sample size term, i.e., a weighting factor such as J_y below, that adjusts the theoretical curve upward or downward to reflect the estimated variability associated with the age-composition sample.

The general form of the objective function used in the two groups of models to derive fishery related parameters are as follows, summation being over $y = 1,\ldots, Y$ for years and $a = 1,\ldots, A$ for ages: (1) least squares (Deriso et al. 1985), choose parameters that minimize

$$\sum_{y=1}^{Y}\sum_{a=1}^{A} [\log_e(c_{ya}) - \log_e(\hat{c}_{ya})]^2; \text{ and,}$$

(2) maximum likelihood (Methot 1990), choose parameters that maximize

$$\sum_{y=1}^{Y}\sum_{a=1}^{A} (J_y)\,(p_{ya})\,\log_e(\hat{p}_{ya}),$$

where c_{ya} is the observed catch-at-age (in number), $\hat{c}_{ya}$ is the predicted catch-at-age (in number), J_y is a weighting factor that reflects the total number of fish in the sample if the fish were selected as a single simple random sample (i.e., if the multinomial probability distribution was strictly correct), p_{ya} is the observed proportion-at-age, and $\hat{p}_{ya}$ is the predicted proportion-at-age. The assumption regarding the pattern of variability exhibited by the actual sample estimates of catch-at-age is generally different between these two groups of models (Figure 4.1).

The primary objective of this research was to examine the statistical properties associated with estimates of age composition for groundfish landings in Oregon from 1989 to 1991. Specifically, I present graphically the distributions of estimated *CVs* associated with estimates of age composition for five species of groundfish to evaluate the appropriateness of the error structure assumption used in fishery models to describe the uncertainty associated with the catch-at-age sample data. Additionally, I present a statistical technique and generally discuss other methods that can be used to determine a 'best fit' curve of the multinomial distribution as applied to particular datasets of age composition. Finally, the results from this study are used to identify some of the drawbacks involved with using a theoretical probability distribution to explain the actual variability associated with landing statistics generated from commercial fishery sampling designs.

METHODS

Landing estimates (in number) and their errors were calculated for five species of groundfish commercially landed at Oregon ports from 1989 to 1991: widow rockfish, yellowtail rockfish, canary rockfish, English sole, and Dover sole. The analyses of age composition for this study were based on a stratified two-stage random sampling design combined with poststratification. The sampling design used for 1989 and 1990 landings incorporated a single sampling unit at the second stage and utilized straightforward ratio estimation techniques to derive landing statistics (Sen 1986). A 'complete' multistage design was used for 1991 landings, which incorporated replicate sampling units at the second stage and used standard two-stage estimators to generate landing estimates (Crone, in press).

A coefficient of variation (*CV*) was used to describe the variation associated with the individual landing estimates of age composition and was calculated as, [(standard error / estimate) • 100]. This statistic is also referred to as a relative standard error (Som 1973) and a coefficient of variation of the estimate (Cochran 1977).

RESULTS

Data points are displayed as the percentage (proportion estimate • 100) of the total annual landings that the individual age groups of a species composed for the years 1989 through 1991 (Figures 4.2 - 4.4). For clarity, I did not include on the graphs the actual ages associated with the data points. Particular ages are used as examples to highlight general patterns exhibited in the graphs. Also, for purposes of graphical clarity, I have omitted age groups that constituted less than 0.07% of the total landings. The *CVs* associated with these estimated minor age components were very consistent across species and years, ranging from 70 to 110%.

The relationship between the individual estimates of age composition, presented as percentages of the total landings, and their associated *CVs* was negatively curvilinear for all five species in all three years (Figures 4.2 - 4.4). In general, estimates that composed large percentages of the total landings were measured with higher relative precision (i.e., had smaller *CVs*) than estimates of age composition that constituted small percentages of the total. For example, 851,558 age-6 English sole were landed in 1991, which was roughly 34% of the total number of English sole landed for the year, and the *CV* associated with this estimate was 13%; whereas, 16,071 age-16 fish were landed, which was approximately 1%

of the total number landed, and this estimate had a *CV* = 87% (star-filled circles, middle right panel of Figure 4.4).

The *CVs* associated with the landing estimates clearly mimicked the curves generated from the theoretical multinomial distributions, presented in the figures for *N* = 100, 400, and 1,000. The role of *N*, i.e., weighting factors, in stock assessment models that incorporate an error structure based on multinomial probabilities is discussed later in this paper. Although the patterns of variation that characterized the estimated age compositions were generally similar between the five species, the amount of statistical 'noise' associated with each set of estimates was not identical. For example, the *CVs* were relatively consistent for the age compositions of widow rockfish and Dover sole, where data points were generally distributed along and slightly below the multinomial probability curve defined by *N* = 1,000. Whereas, *CVs* associated with the age compositions of yellowtail rockfish, canary rockfish, and English sole were more scattered around the theoretical curves than for widow rockfish and Dover sole. For example, each age from 12 to 15 composed roughly 6% (approximately 80,000 fish) of the total landings of yellowtail rockfish in 1991; however, the *CVs* associated with these similar landing estimates ranged from 15 to 25% (star-filled circles, upper left panel of Figure 4.4). For canary rockfish, ages 7, 14, and 15 individually composed approximately 5% (roughly 45,000 fish) of the total landings and the *CVs* ranged from 17 to 33% (star-filled circles, middle left panel of Figure 4.4).

The theoretical distributions more accurately reflected the variation associated with the estimates of age composition that contributed significantly to the total landings than they did for estimates that constituted small percentages of the total, particularly estimates that composed less than 1% of the total. For example, the estimate of 759,068 (approximately 18%) age-7 widow rockfish landed in 1991 had a *CV* = 8% (star-filled circle, upper right panel of Figure 4.4), with *CVs* of 21, 11, and 7% associated with the analogous percentage defined by the multinomial curves for N = 100, 400, and 1,000, respectively. Whereas, the estimate of 3,634 (roughly 0.09%) age-31 widow rockfish had a CV = 59% (star-filled circle, upper right panel of Figure 4.4), compared with *CVs* of 333, 167, and 105%, for the three theoretical distributions defined by N = 100, 400, and 1,000, respectively.

In general, at least three-fourths of the total landings of each species for the years 1989 to 1991 composed a relatively small range of consecutive ages that individually contributed at least 5% to the total and these estimates were relatively precise, with *CVs* less than 25%. The remaining approximately one-fourth of each age composition included comparatively more ages that individually composed less than 5% of the total and these estimates were more variable than for the ages that constituted the three-fourths majority, with *CVs* generally greater than 30% and most often between 50 and 100%. Detailed landing statistics of yellowtail rockfish in 1990 illustrate the general properties of the age-composition sample data collected in Oregon from 1989 to 1991 (Table 4.1).

DISCUSSION

Results presented here indicate that stock assessment models that utilize maximum likelihood estimation techniques with multinomial probability error structure (e.g., Fournier and Archibald 1982; Methot 1989, 1990) more adequately address the variability associated with observed catch-at-age data than models based on lognormal measurement errors. The statistics generated from these analyses clearly show that the *CVs* associated with individual estimates of age composition are not constant, or even approximately so, but rather follow the general properties of a multinomially distributed variable.

Differences in age compositions, statistical and biological, between years precluded using a single multinomial curve to explain adequately the uncertainty associated with the complete set of catch-at-age data for a given species. This was expected given the statistical properties and rigor of the sampling designs used to collect the age-composition information. For example, design intricacies, such as multiple stages, stratification, and weighted estimation methods, precluded the use of explicit theory (e.g., a multinomial distribution supposition) to determine the error associated with the sample estimates of age composition.

The actual estimated variances associated with the landing estimates (in number or percentage) were necessarily derived from appropriate sample estimation techniques that required no assumptions regarding distribution properties of the measurement variables. That is, multinomial distribution theory could be applied to a single random sample from a boat trip in a generally straightforward fashion, e.g., to calculate the variance associated with the estimated proportion of age-6 yellowtail rockfish in the landings. However, strict reliance on a theoretical probability distribution to determine the sampling error associated with a landing estimate can lead to misleading conclusions, given that: (1) as discussed above, many sampling designs are inherently complex and do not necessarily produce results with stochastic properties that adhere rigidly to a known probability distribution; and, (2) known sample selection biases and other unplanned, nonrandom protocols involved in most fishery sampling programs results in datasets that are only nominally random, which invalidates using a theoretical distribution to determine definitively the actual sampling error associated with the landing estimates. Random sample hypotheses relied upon in fishery monitoring programs are operationally convenient; however, the appropriateness of such assumptions needs to be examined on the bases of the individual fishery and stock assessment approach. Kimura (1990) also argues that although rigorous multinomial sampling for catch-at-age data may be convenient from an intuitive or modelling standpoint, it is most often an impractical sample selection approach, given the expanse and dynamics of commercial fisheries.

It would be beneficial from a model fitting standpoint to adjust the weighting factor, used in the model as a scaling variable to denote the 'sample size' and subsequent curve of the theoretical distribution, in accordance with the *CVs* associated with the landing estimates of age composition. Adjusted weighting factors would further decrease the amount of bias associated with the analyses and should be addressed before modelling procedures are undertaken. I follow Methot (1990) and use the term weighting factor instead of sample size to differentiate between the theoretical sampling units (individual fish that compose an age-composition sample, *f* in Figures 4.2 - 4.4) as treated in a multinomial probability distribution and the actual sampling units associated with most commercial fishery sampling designs, such as boat trips, market categories, and baskets of fish (Tomlinson 1971; Crone, in press). For example, although 4,614 individual fish were included in the entire sample dataset of age composition for Dover sole landed in 1991, the sampling design utilized estimators based on a sample size of 90 boat trips. Weighting factors need to be considered carefully, given that they are integral components in model processes and strongly influence the manner in which the models attempt to fit the data. In particular, large weighting factors can produce generally undesirable effects because these attributes will tend to govern strongly the fit produced by a model (Fournier and Archibald 1982; Methot 1990) and thus, inherently overshadow other important components considered in the fitting procedures. Fournier and Archibald (1982) suggested that a weighting factor less than 400 be used to define the multinomial error structure utilized in their model.

Results presented here indicate it would be difficult to determine by visual inspection a weighting factor that accurately generates a curve similar to the estimated *CVs* calculated from the sample data, given the aspect of differential noise in the age compositions of a given species across years (Figures 4.2 - 4.4). However, as stated earlier, some species had age compositions that were characterized by fairly consistent measures of dispersion across years and in these cases it is plausible that a single theoretical curve (e.g., $N = 1{,}000$ for widow rockfish landings from 1989 to 1991) could be selected that adequately describes the actual estimated variability associated with a complete set of catch-at-age data of a given species. Additionally, it seems reasonable that appropriate weighting factors could be derived using some of the general properties of commercial fishery sampling designs. For example, Shepherd and Nicholson (1991) present an intuitively attractive method based on fitting procedures that incorporate weighted residual analyses, which ultimately produces results generally similar to those generated from a multinomial distribution error structure. Although general methods, such as the approach proposed by Shepherd and Nicholson, do provide results that are broadly appropriate, the actual catch-at-age data may be much more or less precise than the results indicate, due largely to the effectiveness of the sampling design.

Weighting factors can be adjusted to reflect the specific properties of a particular age-composition dataset using more objective criteria than utilized in visual diagnostics or general methods. The motivation behind the techniques I discuss below is presented in Shepherd and Nicholson (1986, 1991); however, the authors present analyses that can be used to identify a variance structure that attempts to define landing estimates of age composition in general. I present methods that can be utilized to determine the most appropriate weighting factor to describe the variation associated with a specific age composition(s), thus these methods require that the actual variance measures associated with the sample estimates be available.

To determine the most appropriate theoretical curve that describes the variability associated with the sample estimates of age composition, relatively straightforward nonlinear regression estimation methods could be employed. For example, the multinomial curve that best describes the results from analyses of age composition presented here is defined as the line that results in the smallest residual sum of squares statistic based on the criterion of least squares. Using this technique, pooled 1989 to 1991 age-composition results for yellowtail rockfish showed that a weighting factor (*N*) equal to 1,119 defined the best multinomial curve for the sample data. Only landing estimates of individual ages that composed at least 0.07% of the total annual landings for the years 1989 to 1991 were included in the analysis. The value 1,119 is somewhat larger than visual examination of the plots would suggest (upper left panels of Figures 4.2 - 4.4) and considerably larger than the maximum value of 400 recommended for stock assessment models that are based on a maximum likelihood estimator and multinomial probability error structure. The large weighting factor was primarily due to two reasons previously discussed in the Results: (1) the disproportionately large number of ages that composed small percentages of the total landings (e.g., see Table 4.1 for age-composition estimates of yellowtail rockfish landings in 1990); and, (2) the inability of the theoretical curves to adequately describe the variance associated with these ages.

As is the case with regression analysis procedures in general, the researcher may be interested in a specific portion of the distribution of sample estimates and thus, would like to emphasize a subset of the complete age composition in the analysis, e.g., determine a weighting factor for only those ages that composed at least 1% of the total landings. If assessments are most interested in those ages that composed large percentages of the total landings of a species, a weighted least squares technique would produce a more appropriate statistic than an unweighted procedure. Another possible corrective measure that would ideally account for variability in the age-composition sample data presented here would be to apply separate error structures for small versus large proportion estimates, recognizing that the model fitting procedures will become more complicated to some degree.

Research objectives that address the impact of various error structures on model results have received sparse attention in fishery science (Megrey 1989). Intuitively, a model should be designed in a manner that allows the correct stochastic properties of the catch-at-age data to be incorporated, otherwise additional sources of bias are inherently introduced into the analytical processes. Methot (1990) suggested that the multinomial error structure is a preferred model feature because it emphasizes the variation associated with landing estimates that reflect large proportions of the total landings, which are documented here as being comparatively more precise than the estimates that constituted small proportions of the total. An experiment conducted to examine the sensitivity of assessment results to the assumption of constant selectivity showed that the assumed error structure could have a large impact on the final estimates generated from two different modelling approaches, namely stock synthesis analysis and Catch AGE ANalysis or CAGEAN (Sampson 1993).

In contrast, Deriso et al. (1985) demonstrated that a stock assessment model that utilized a least squares estimator (CAGEAN) generated similar results in a comparative study of three different theoretical distributions, based on lognormal measurement error, multinomial measurement error, and process error, applied individually to the model to address the stochastic properties of hypothesized catch-at-age data. Kimura (1990) simulated catch-at-age data using lognormal and multinomial error structures and then analyzed the data using nonlinear least squares and multinomial maximum likelihood estimation, and showed that the results from the overall analyses were very similar. The author did however recommend that caution be used when interpreting his findings, given that the results from the simulation experiments may depend strongly on the population and constraints utilized in the model.

Further research is needed that focuses on the relationship between departures from assumptions and model output to examine critically the issue of statistical robustness of fishery models. The results and discussion presented here are used to evaluate the appropriateness of an assumption used in age-structured assessment models to address the stochastic properties of catch-at-age data and should not be interpreted as broad recommendations of the overall performance of a model, given that these assessment methods incorporate a host of estimated parameters and other assumptions that were not investigated in this study.

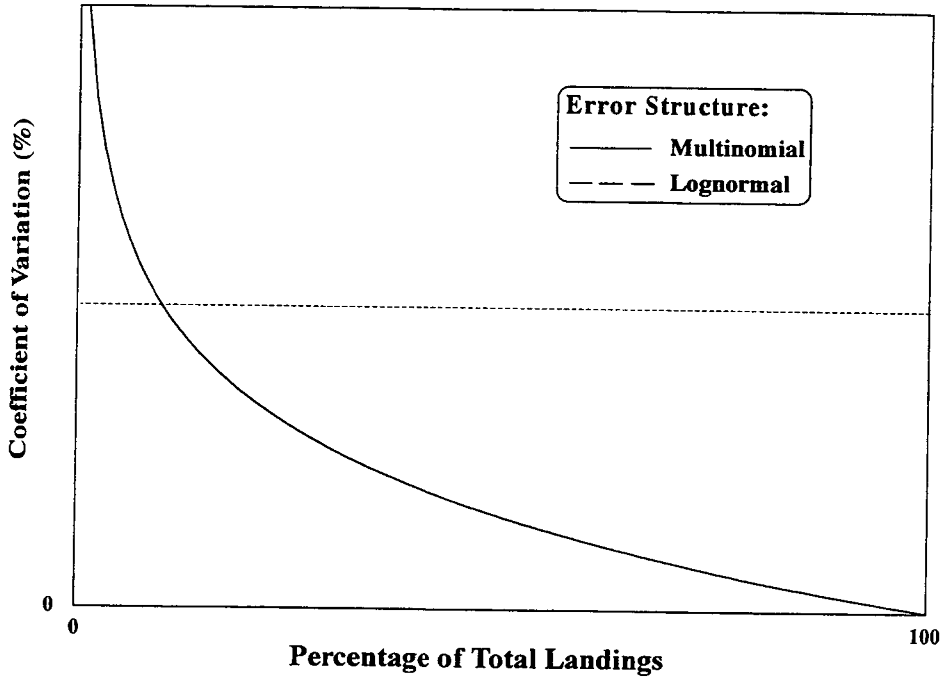

Figure 4.1. Distributions of estimated coefficients of variation (%) associated with estimates of age composition (percentage of total landings) for two different error structure assumptions used in fish stock assessment models. Lines depict the general form of the distributions and do not reflect the inherent variability associated with samples of age composition.

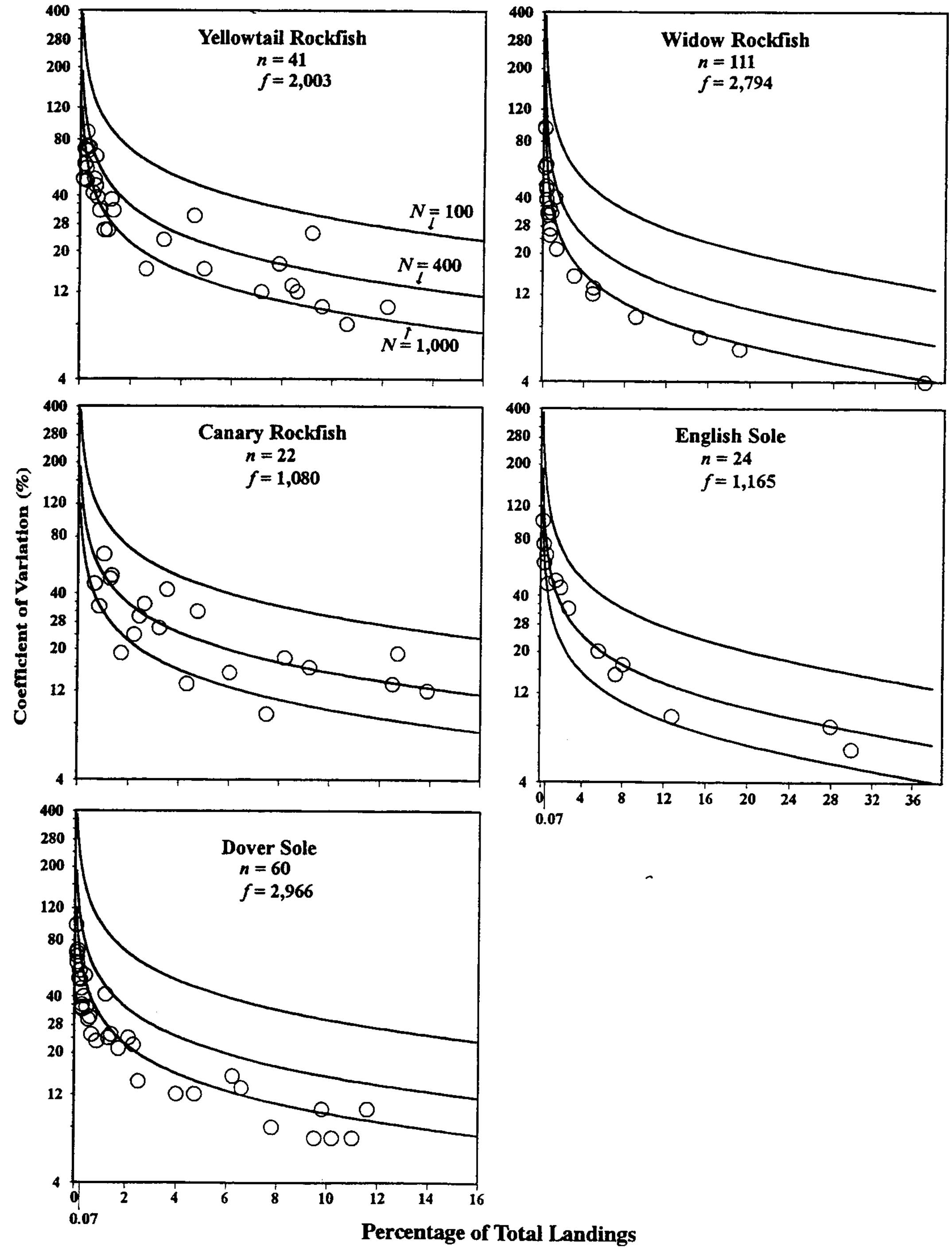

Figure 4.2. Distribution of estimated coefficients of variation (%) associated with estimates of age composition (percentage of total landings denoted by circles) for five species of groundfish landed at Oregon ports in 1989. Coefficients of variation derived from percentage estimates of three theoretical multinomial distributions are presented, N = 100, 400, and 1,000. Estimates for ages that composed at least 0.07% of the total landings are included. The Y-axis has been logarithmically scaled. For each species, the sample sizes (number of boat trips) used to derive landing statistics are denoted as n and the total number of fish collected across all boat trips is denoted as f.

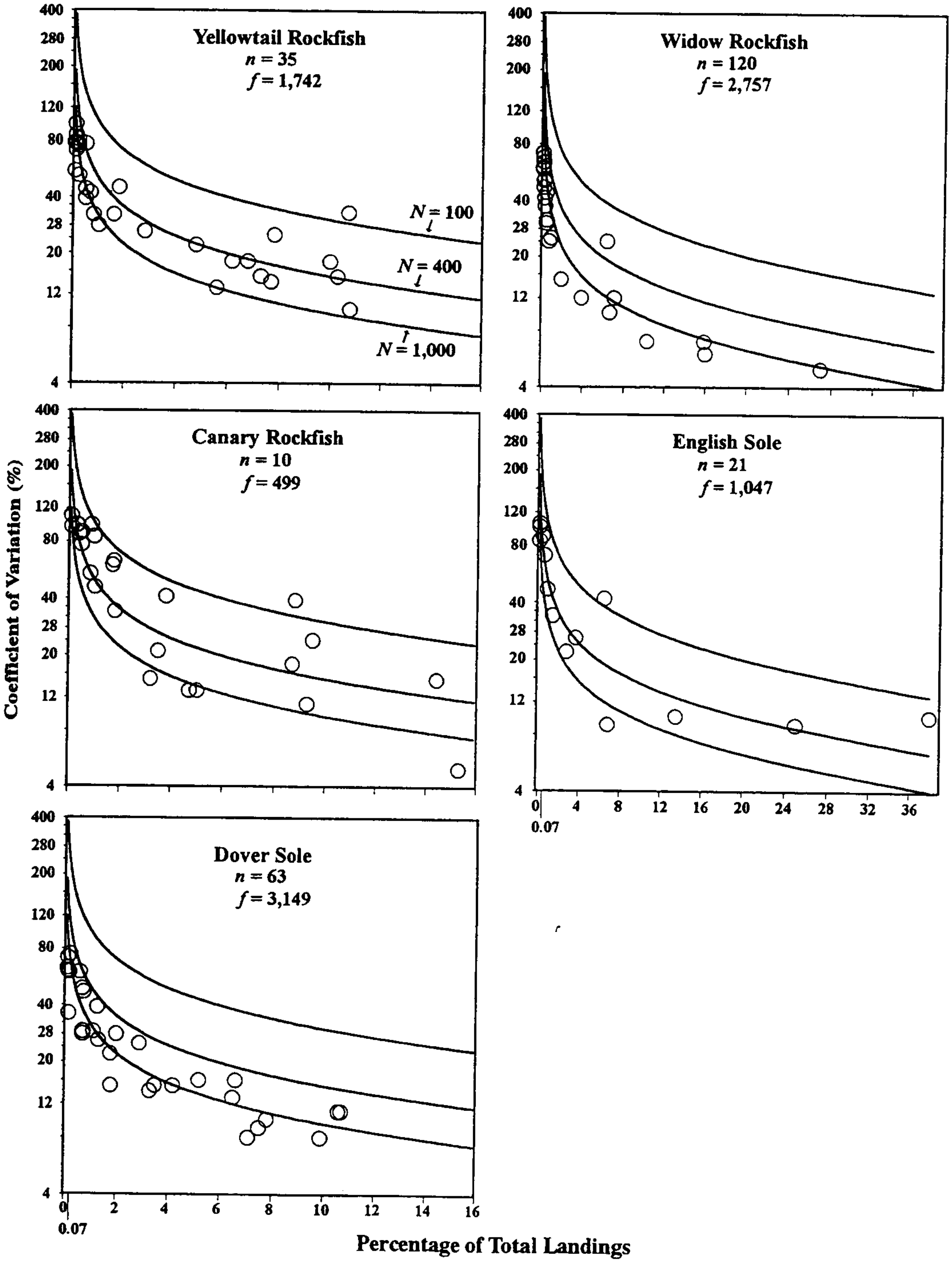

Figure 4.3. Distribution of estimated coefficients of variation (%) associated with estimates of age composition (percentage of total landings denoted by circles) for five species of groundfish landed at Oregon ports in 1990. Coefficients of variation derived from percentage estimates of three theoretical multinomial distributions are presented, N = 100, 400, and 1,000. Estimates for ages that composed at least 0.07% of the total landings are included. The Y-axis has been logarithmically scaled. For each species, the sample sizes (number of boat trips) used to derive landing statistics are denoted as n and the total number of fish collected across all boat trips is denoted as f.

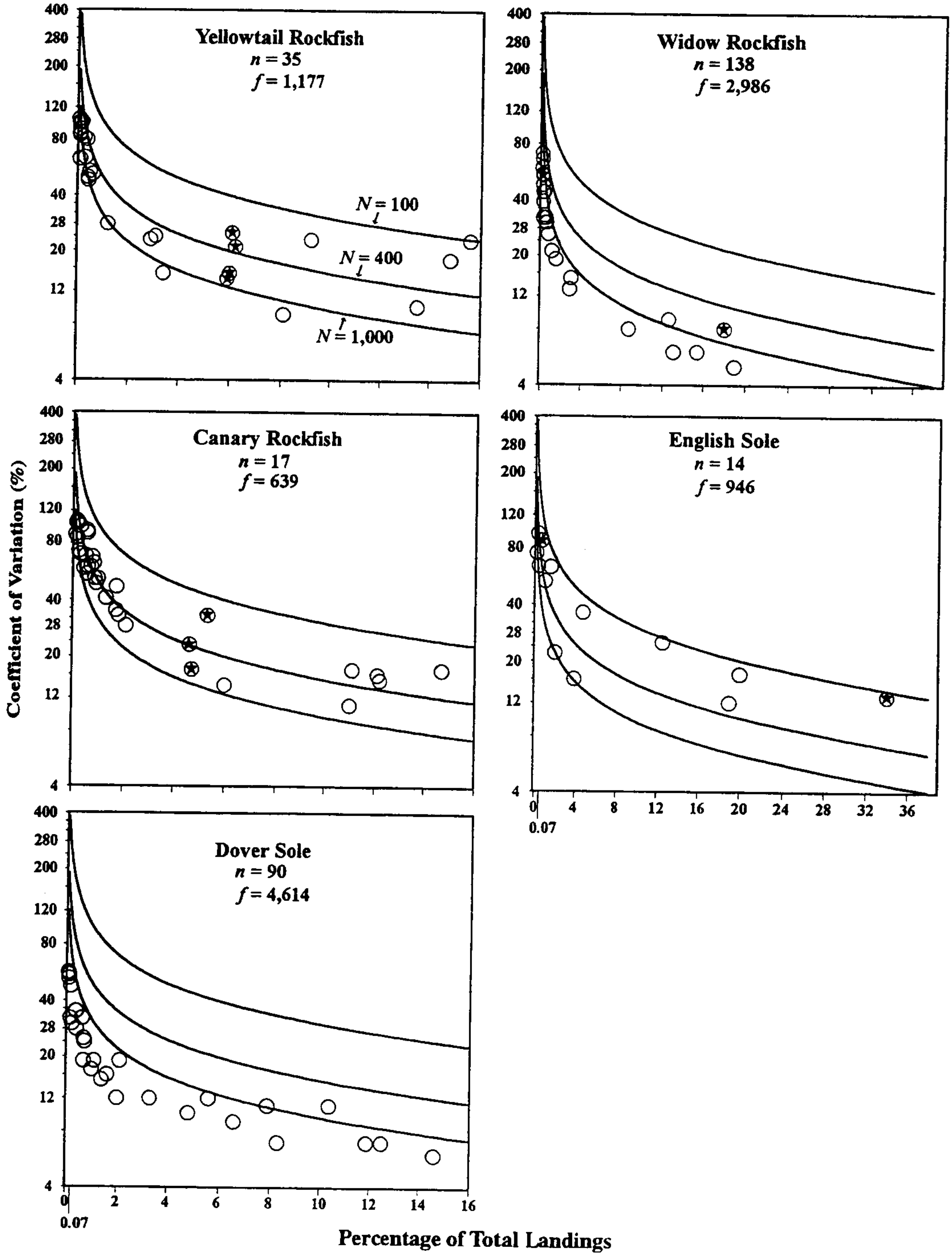

Figure 4.4. Distribution of estimated coefficients of variation (%) associated with estimates of age composition (percentage of total landings denoted by circles) for five species of groundfish landed at Oregon ports in 1991. See Results section for description of star-filled circles. Coefficients of variation derived from percentage estimates of three theoretical multinomial distributions are presented, N = 100, 400, and 1,000. Estimates for ages that composed at least 0.07% of the total landings are included. The Y-axis has been logarithmically scaled. For each species, the sample sizes (number of boat trips) used to derive landing statistics are denoted as n and the total number of fish collected across all boat trips is denoted as f.

Table 4.1. Age-composition estimates for yellowtail rockfish landings in Oregon (1990). Landing estimates are in number of fish. $n = 35$ boat-trip samples.

Age	Landing estimate	Percent of total landings	*CV* (%)
4	236	<1	102
5	23,759	2	45
6	140,419	11	33
7	132,329	10	18
8	81,400	6	18
9	135,648	10	15
10	142,835	11	10
11	96,412	7	15
12	101,234	8	14
13	89,401	7	18
14	102,838	8	25
15	74,107	6	13
16	62,956	5	22
17	37,099	3	26
18	21,001	2	32
19	13,310	1	28
20	6,461	<1	39
21	10,613	1	32
22	1,142	<1	55
23	8,852	1	42
24	1,000	<1	78
25	1,457	<1	86
26	1,464	<1	71
27	6,556	<1	44
28	6,479	<1	77
29	3,134	<1	52
30	2,911	<1	81
31	2,634	<1	77
32	90	<1	102
34	1,638	<1	78
36	701	<1	100
37	393	<1	101
38	392	<1	101
40	43	<1	103
41	2,786	<1	75
42	1,638	<1	78
46	1,245	<1	98
Total	1,316,613	100	

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CHAPTER 5

SPATIAL DIFFERENCES IN MATURITY SCHEDULES OF FEMALE DOVER SOLE LANDED AT OREGON PORTS (1989-91)

ABSTRACT

An assessment of sexual maturity of Dover sole landed in Oregon from 1989 to 1991 indicated that females of the species had a 50% probability of being mature at ages 7.3 to 9.5, depending on when and where the sampling was conducted. Logistic regression models were used to document statistical differences ($P \leq 0.05$) between maturity schedules of fish harvested in the northern and southern regions of the state. There was evidence that fish from southern Oregon waters reached sexual maturity at an earlier age and exhibited higher overall rates of maturity than fish inhabiting northern waters of the state. It does not appear that the statistical findings are of magnitudes that reflect dramatic implications for management, primarily because the vast majority of the fish (at least 90%) did not enter the fishery until mature. It is recommended that additional information be collected regarding other vital parameters of the species, such as estimates of growth rates and mortality coefficients, to ensure exploitation strategies appropriately address the stock structure of Dover sole inhabiting Pacific coast waters.

INTRODUCTION

Dover sole inhabiting waters off the Pacific coast of the United States have been utilized as a valuable commercial resource for the past 50 years (Yoklavich and Pikitch 1989; Westrheim et al. 1992). Annual landings of Dover sole from 1984 to 1992 have contributed substantially to the total landings of groundfish of the Pacific coast region (California, Oregon, Washington), where approximately 16,000 to 21,000 tonnes have been landed on a yearly basis (PFMC 1993).

The management of fishery resources, such as the Dover sole fishery of the Pacific coast, is necessarily based on the life history characteristics of the exploited species. Harvest strategies that minimize detrimental effects to the fish resources are largely dependent on scientific analyses of the biological characteristics of commercial landings (Gulland 1983). Stock assessments inherently rely on the availability of information regarding the 'stock parameters' of the exploited species, such as growth, reproduction, and mortality (Shepherd 1988). From a management standpoint, an essential property of a stock is that the parameters that define it remain more or less constant throughout its area of distribution (Sparre et al. 1989). That is, fish stock assessments should be made for each stock separately. Scientific evaluations of the stock parameters of a species, along with studies that address their genetic and migratory characteristics, provide information that together are used to define the stock(s) structure of the marine resource. Henceforth, I use the term 'stock' in the broad context of fish stock assessment and define it following Gulland (1983): "a group of organisms can be treated as a stock if possible differences within the group and interchanges with other groups can be ignored without making the conclusions reached depart from reality to an unacceptable extent."

The objective of this paper was to evaluate statistically the spatial similarity of reproductive parameters of Dover sole inhabiting marine waters off Oregon. Tagging studies have demonstrated that Dover sole exhibit relatively little latitudinal movement in Pacific coast waters (Westrheim and Morgan 1963; Westrheim et al. 1992; PFMC 1993), which indicates the fish may exist as independent stocks with distinct parameters. Additionally, I evaluate estimates of age composition for commercial landings of Dover sole along with the maturity assessment to determine the practical implications for management. The sexual maturity information presented here is a critical component of a complete analysis of the Pacific coast Dover sole fishery, and these results can be directly utilized by management to assess the urgency for separate management policies concerning this groundfish species.

METHODS

Study Design

Dover sole commercially landed at Oregon ports from 1989 to 1991 were analyzed in this study (Table 5.1). Fish were classified by region according to the location of the harvest using the following coordinate criteria: (1) the north region was from 45°04' N latitude to 47°20' N latitude, including the triangle that is drawn at 220° from 48°29'34" N latitude, 124°43'27" W longitude; and, (2) the south region was from 42°25' N latitude to 44°18' N latitude (Figure 5.1). Boat-trip harvests in the north region were landed at the ports of Astoria and Garibaldi and catches in the south region were landed at the ports of Charleston and Brookings. In general, longitudinal boundaries were not used to define regions, primarily because this component of the sampling design was accounted for by examination of a depth variable in the statistical analyses.

The sexual maturity data were separated into 'homogeneous' time blocks to account for the physiological changes that occur in fish in preparation for and during spawning. It has been demonstrated that the time of sampling is an important variable in maturity studies of Dover sole (Hunter et al. 1992) and thus, analyses should consider this variation to ensure results do not include additional sources of bias that would hamper statistical interpretation.

The spawning season for Dover sole off the Pacific coast from central California to Oregon is generally considered to occur within a six-month period, from approximately December to May (Hunter et al. 1992). However, the exact date that spawning begins and ends in any given year cannot be defined exactly, given that the reproductive cycles of fish are closely related to environmental changes, particularly seasonal changes in light and temperature (Moyle and Cech 1982). I treated the months from June through November as the non-spawning period and the months from December through May as the spawning period (Table 5.1).

All Dover sole specimens used in this study were collected as part of a broad sampling program conducted by the Oregon Department of Fish and Wildlife to determine various statistics associated with the commercial landings of groundfish species. Many of the regulated fisheries of the Pacific coast, such as the Dover sole fishery in Oregon, are routinely sampled to determine primarily the age composition of the landings and additionally, to obtain other demographic attributes of the catch, such as length frequency distributions and maturity states. Information was also collected regarding particular attributes of the fishing trip, such as depth at which fish were caught and gear type used. The sampling designs used to collect these landing data were stratified two-stage random sampling plans combined with poststratification (see Chapters 2 and 3, Methods, Age-composition Sampling Program).

Sampling duties were the responsibility of two port biologists, an individual assigned to the north region (ports of Astoria and Garibaldi) and another assigned to the south region (ports of Charleston and Brookings). Both port biologists participated in similar training programs and were given identical sampling instructions. Technical support personnel stationed at the regional headquarters in Newport supervised field procedures and routinely conducted meetings to ensure sampling was performed in a standardized fashion.

Sexual Maturity Determination

Only female Dover sole specimens were used in analyses presented here. Maturity assessments of individual fish were made by gross anatomical examination of ovaries and oocytes and a classification scheme similar to the multiple reproductive stage scale proposed by Hagerman (1952). Ultimately, fish were assigned as mature or immature based on the following criteria. Fish were considered mature in cases where: (1) ovaries contained developing or mature ova (yolked or partially yolked oocytes); or, (2) ovaries were recently spent or in the later phases of recovering. Fish were considered immature in cases where ovaries were undeveloped and contained no visible signs of developing or mature ova.

The primary advantages of a field based procedure, such as the gross anatomical examination technique, is that it utilizes relatively simple criteria to assess reproductive states, requires limited manpower and money to administer, and provides generally informative data for management purposes. However, there are more elaborate and definitive techniques to identify states of sexual maturity in species of fish than the gross anatomical examination method. For example, it has been demonstrated that a detailed histological examination of ovaries provides more reliable information than that obtainable from macroinspection techniques employed in the field (Hunter et al. 1992). A major drawback associated with the histological techniques is that they are laboratory based methods, which are often not logistically or financially feasible within the constraints of many commercial fishery management programs.

Age Determination

Otoliths were collected from each fish (specimen) at the sampling sites and temporarily stored in vials for future processing. The following data were generally recorded for each specimen: species, specimen number, length of fish, weight of fish, and port and date sampled. Otoliths were then immediately sent to a centrally located age-reading laboratory in Newport.

A break and burn technique was used to prepare otoliths for ageing (Christensen 1964). The break and burn procedure has been demonstrated as a reliable technique for ageing Dover sole otoliths by annual zonation (Chilton and Beamish 1982) and is currently the method used in ageing programs for Dover sole that are routinely conducted by fishery management agencies in the United States and Canada. No validation studies have been conducted to assess the accuracy of age determination techniques for Dover sole (Yoklavich and Pikitch 1989). However, ageing studies and workshops conducted by the state fishery agencies of Oregon and Washington and the Department of Fisheries and Oceans of Canada have generated several unpublished reports that generally support the break and burn method as a 'valid' technique that can be used to identify annual bands on otoliths of Dover sole (R. L. Demory and R. Mikus, Oregon Department of Fish and Wildlife, Newport, Oregon, personal communication). A 15% subset of all age samples was analyzed by a second reader to determine the reliability of the age estimates. Analyses presented here incorporated sample data that reflected 100% agreement between readers.

Statistical Analysis Procedures

Data were analyzed with logistic regression. The response variable (i.e., sexual status of a fish) in the analysis was treated as a binary variable (i.e., mature or immature) and a logistic regression model was fitted for a set of explanatory variables that included region as a factor (indicator variable), age as a continuous variable, and the interaction between age and region. Logistic response functions have been found to be appropriate and effective statistical tools to describe generally the proportion of sexually mature fish in a population, for both marine and freshwater species (Hunter et al. 1990; Munger et al. 1994). The aptness of the logistic regression model was investigated following informal goodness of fit examinations (Neter et al. 1989) and residual diagnostics (Hosmer and Lemeshow 1989; Agresti 1990). Model diagnostic procedures based on R^2 measures were not utilized in analyses presented here because of the limitations of these statistics when applied to binary response variables (Agresti 1990).

The estimated logistic response function used in these analyses was,

$$\hat{p}_m = \frac{e^{(b_0 + b_1 \bullet age + b_2 \bullet region + b_3 \bullet age * region)}}{1 + e^{(b_0 + b_1 \bullet age + b_2 \bullet region + b_3 \bullet age * region)}}, \qquad (5.1)$$

where $\hat{p}_m$ is the estimated probability that a fish is mature and the estimated regression coefficients are b_0 for the intercept, b_1 for age, b_2 for region, and b_3 for age*region. The response variable $\hat{p}_m$ can be practically interpreted as an estimated proportion or percent. The linearized form of the estimated logistic response function above, referred to as the estimated logit response function, illustrates the statistical relationship between logistic and general linear models,

$$\log_e\left(\frac{\hat{p}_m}{1-\hat{p}_m}\right) = b_0 + b_1\bullet age + b_2\bullet region + b_3\bullet age*region\,, \tag{5.2}$$

where $\log_e[\,\hat{p}_m\,/\,(1\,-\,\hat{p}_m)]$ is the estimated logit.

The estimated logistic response function, equation (5.1), yields the fitted regression lines (i.e., maturity schedules or curves) for both the north region and south region. Equations (5.1) and (5.2) are referred to as the 'full' models in the statistical tests. Fitting this type of logistic response function generates the same results as fitting separate regressions for the north region and south region. Because region is treated as an indicator variable, a simple logistic model is generated for each region, which is analogous to fitting the single explanatory variable age to separate regression models for the north region and south region. This statistical modelling technique was used because it allowed straightforward tests to be conducted for comparing parameters (regression coefficients, β) of the curves between the two regions.

The method of maximum likelihood was used to estimate the parameters of the logistic response functions. Analysis of deviance procedures (McCullagh and Nelder 1989) were used to assess the significance of particular models and document whether the two regions had statistically different logistic response functions. Because 'over-dispersion' (extra-binomial variation) has been demonstrated to occur frequently in logistic regression methods involving binary data, I conducted analysis of deviance procedures (drop-in-deviance *F*-tests) that assumed the existence of extra-binomial variation (Baker and Nelder 1985; McCullagh and Nelder 1989; Ramsey and Schafer, in press). To account for extra-binomial variation in the analyses, a quasi-likelihood approach was used to adjust the inferences obtained from the drop-in-deviance F-tests (McCullagh and Nelder 1989). The drop-in-deviance adjusted value is referred to as the deviance test statistic.

The above tests are motivated by linear regression theory and least squares estimation, in particular the extra sum of squares approach for tests about regression coefficients. The tests are analogous to analysis of covariance procedures used to compare statistical parameters of two or more linear regression lines.

Specifically, formal tests were conducted for two 'reduced' models within each time block. First, the presence of interaction effects (b_3 for age*region) was tested to determine whether the two logistic curves had equal slopes at the age at which there was a 50% probability that a fish was mature ($\text{Age}_{50\%}$):

$$H_0\colon \beta_3 = 0,$$
$$H_A\colon \beta_3 \neq 0.$$

Secondly, the significance of the estimated regression coefficients for region (b_2) and age*region was examined to determine whether there was a statistical difference in the elevations (vertical positions) of the two logistic curves at $\text{Age}_{50\%}$. This test examines whether the two maturity curves are 'statistically identical' to one another (Neter et al. 1989):

$$H_0\colon \beta_2 = \beta_3 = 0,$$
$$H_A\colon \text{not both } \beta_2 \text{ and } \beta_3 = 0.$$

Applying large-sample theory, the distribution of the deviance test statistic is approximated by the F distribution, $F_{(r-f,f)}$, when H_0 holds. Values for the degrees of freedom associated with the distribution are denoted as r and f, for the reduced and full models, respectively.

Note that the sigmoid shape of a logistic curve prevents using straightforward linear regression methods to determine a single value that describes the slope of a curve. Rather, the odds ratio interpretation of the estimated regression coefficient b_1 in a simple logistic model is commonly used to evaluate the rate at which the line increases or decreases. Odds ratios presented here can be practically interpreted as the estimated percent increase in the odds of a fish being mature with each one-year increase in age. Odds ratios were estimated from the simple logistic response function of each region as, $\exp(b_1)$, where b_1 was the estimated regression coefficient for the explanatory variable age. Confidence intervals (95%) were constructed for odds ratios to provide a measure of the variability associated with these statistics (Neter et al. 1989). The age at which there was a 50% probability that a fish was mature ($\text{Age}_{50\%}$) was calculated from the simple logistic response function of each region as, $-b_0 / b_1$, where b_0 was the estimated intercept and b_1 was the estimated regression coefficient for the explanatory variable age.

As discussed previously, the purpose of this study was to evaluate the similarity of maturity schedules of Dover sole between fish harvested and landed in the northern region and southern region of Oregon. Thus, I developed two suites of 'descriptive' models that included explanatory variables of interest and then compared these models using straightforward statistical inference procedures. This study was not concerned with developing a 'predictive' model that included various explanatory variables (such as water temperature, salinity, upwelling indices, etc.), which could be used as the 'best available' prediction tool to determine whether a fish would be mature or immature.

Because it has been demonstrated that the proportion of sexually mature female Dover sole increased with depth (Hunter et al. 1990), I performed preliminary analyses using analysis of variance procedures to determine whether fish were harvested (i.e., sampled) from similar depths between the north and south regions. The depth at which fish were harvested for each boat-trip sample was treated as the measurement variable in an analysis of variance design that consisted of two treatment groups (north region and south region). The statistical power of the analysis of variance tests was estimated following Zar (1984). A formal investigation of the depth variable served two primary purposes in this study: first, to ensure that a sampling bias was not present in the study design, which would have impeded statistical interpretation of the results; and second, to evaluate the a priori importance of an explanatory variable in the models. A depth variable was only indirectly related to the study objective, which required I develop models that were based on a relevant and interpretable set of explanatory variables and exclude covariates that had no meaningful effect on the comparisons of interest.

RESULTS

Results are presented separately for the 'Before' time block (spawning period) and the 'During' time block (non-spawning period). Standard model-checking procedures showed that estimated response functions were monotonic and sigmoidal in shape and that logistic regression was an appropriate tool to analyze and model the maturity datasets of Dover sole.

Depths at which fish were harvested were not significantly different between the north and south regions for both time blocks, $P = 0.12$ for Before and $P = 0.08$ for During. Additionally, the depth variable was generally not a significant ($P > 0.05$) covariate in preliminary model selection analyses. That is, statistical evidence supported the hypothesis that samples were taken at similar depths between the two regions and thus, this term was omitted from the final models. Note, that there was low statistical power ($P \cong 0.30$) associated with the analysis of variance tests that addressed the significance of a depth variable between regions. However, given the objectives of the study, I felt that tests associated with relatively low power were not reason alone to include a statistically non-significant term in the subsequent analyses.

The maturity schedules were statistically different (i.e., not identical) between the north and south regions for both time blocks (Figures 5.2 and 5.3), $P = 0.05$ for Before and $P < 0.01$ for During (Table 5.2). These statistical findings indicated that female Dover sole from the south region matured at an earlier age than fish from the north (e.g., see Age at 50% mature in Table 5.3). However, a lack of younger fish, which were needed to define the maturity schedules for years one through five, precluded examining the properties of the curves for estimated proportions generally less than 40%. Additionally, comparisons that address age at first maturity depend on the proportion of interest, which varies in accordance with management objectives and the reproductive potential of the exploited species.

Tests that addressed the significance of the interaction term, age*region, were inconclusive (Table 5.2). For the During time block, the slopes of the maturity curves at $\text{Age}_{50\%}$ was significantly different ($P = 0.05$) between the two regions; however this parameter of the logistic curves was not significantly different ($P = 0.72$) between regions for the Before time block.

Odds ratio estimates, i.e., the estimated percent increase in the odds of a fish being mature with each one-year increase in age, were similar between regions for the Before time block (north = 41% and south = 37%), but considerably higher for the south region (43%) than the north region (25%) for the During time block (Table 5.3). Estimated 95% confidence intervals for the odds ratios indicated that these statistics were variable and not statistically different between regions within each time block ($P > 0.05$).

Estimates of age composition for commercial landings of Dover sole from 1989 to 1991 showed that roughly 10 to 20% of the total landings of Dover sole composed fish less than

10 years old (see Chapters 2 and 3, Results, Age-composition Sampling Program). Roughly equal amounts of Dover sole were harvested from the north and south regions during the study period (e.g., approximately 3,000 metric tonnes in each region in 1990) and the total landings in each region consisted of approximately equal numbers of males and females. Results presented here (Figures 5.2 and 5.3) indicated that female Dover sole between the ages of 7.3 and 9.5 had a 50% probability of being mature, depending on where and when sampling took place. Thus, a first approximation for the percentage of the total landings of female Dover sole that were immature ranged from 5 to 10%.

DISCUSSION

In general, results from statistical tests indicated that female Dover sole exhibited different maturity schedules between the north and south regions; however, analyses were not conclusive for the Before time block. The maturity curves for the south region were very similar across time blocks; however, the maturity curves for the north region were considerably different for each time block, which may have been due to the small number of samples collected from this region for the Before time block.

Previous research has demonstrated that estimates of length or age at first maturity may be influenced by time of sampling and that these statistics should be derived from samples that are collected prior to the onset of spawning, i.e., during the Before time block (Hunter et al. 1992). This recommendation is based on the premise that gross anatomical examinations of reproductive organs are more likely to be biased during the spawning season than before spawning begins, primarily because during the spawning season ovaries of some post-spawning females regress substantially, which often precludes distinguishing these fish from immature females (Hunter et al. 1992). Additionally, because commercial fishers may target on spawning aggregations, samples collected from landings of Dover sole during the spawning period may contain high numbers of mature fish and thus, not reflect the population(s) at large. Because characteristics of the reproductive parameters of fish are strongly influenced by spawning processes, it is imperative that research studies account for these physiological changes when developing sampling designs for maturity assessments. Sampling schedules that are not rigorously defined in accordance with management objectives will likely produce information that is biased and subject to misleading conclusions.

The statistical differences documented here do not warrant substantial departures from the management approach currently in place for the Dover sole fishery off Oregon. That is, given that the vast majority of female Dover sole commercially landed in Oregon from 1989 to 1991 were sexually mature fish, it is not recommended that different management strategies be adopted at this time for the north and south regions. However, without additional information it would be difficult to assess the relationship between the differences documented here and the intricacies involved in stock assessment modelling used to determine appropriate quota levels for this species.

Previous researchers have suggested that spatial differences existed in maturity schedules of Dover sole stocks inhabiting Pacific coast waters (Yoklavich and Pikitch 1989; Hunter et al. 1990). However, it is very possible that these differences were due solely to differences in sampling designs and methods used to assess sexual maturity of the fish specimens (Hunter et al. 1992). The work presented here was based on similar sampling techniques, personnel, and maturity assessment criteria, which allowed results to be interpreted with relatively high certainty, recognizing the limitations and potential error of the gross anatomical examination method.

In the absence of genetic information regarding the Dover sole stock(s), management has primarily utilized tagging and biological research to develop harvest strategies. Adult Dover sole off Oregon that do not remain in deep water throughout the year do not appear to make long latitudinal migrations; however, the larvae spend up to one year in pelagic areas far offshore, which suggests that ocean conditions may cause 'individual stocks' to undergo considerable mixing (Pearcy et al. 1977; Westrheim et al. 1992). The amount of mixing between the genetic pools, along with environmental factors, are processes generally considered to influence strongly the vital parameters, such as maturity, associated with a species (Hanski and Gilpin 1991). It is not possible to identify precisely the factors that contributed to the findings presented here. Regardless, the results from this work allow management to proceed with increased certainty under current fishery operations, while other research studies can be developed to ascertain causal factors.

It is recommended that future maturity assessments incorporate young fish, pre-recruit ages, so that maturity schedules can be developed that are based on the entire age composition of a Dover sole stock. Studies that address fecundity, growth, and mortality of the population(s) off Oregon would allow more definitive conclusions to be drawn regarding the differences in vital parameters of the exploited fish stocks and the subsequent management directions taken. Proper assessments can only be carried out when the biology of the species is fully understood; this information is critical to management, which largely develops harvest policies based on the growth potential of fish populations.

Table 5.1. Sampling design used to collect Dover sole specimens in Oregon. All samples were obtained from commercial landings using a two-stage random sampling design.

Date (year/month)	Time block (spawning period)[a]	Sample sizes			
		Number of boat trips		Number of fish	
		North	South	North	South
1989					
Jan - May, Dec	During	15	8	278	183
Jun - Nov	Before	6	10	121	215
1990					
Jan - May, Dec	During	13	12	322	233
Jun - Nov	Before	2	11	77	203
1991					
Jan - May, Dec	During	19	17	473	314
Jun - Nov	Before	2	16	49	358
1989-91					
Jan - May, Dec	During	47	37	1,073	730
Jun - Nov	Before	10	37	247	776

[a] Before denotes samples were collected before the spawning period while fish were not actively spawning and During denotes samples were collected during the spawning period while fish were actively spawning.

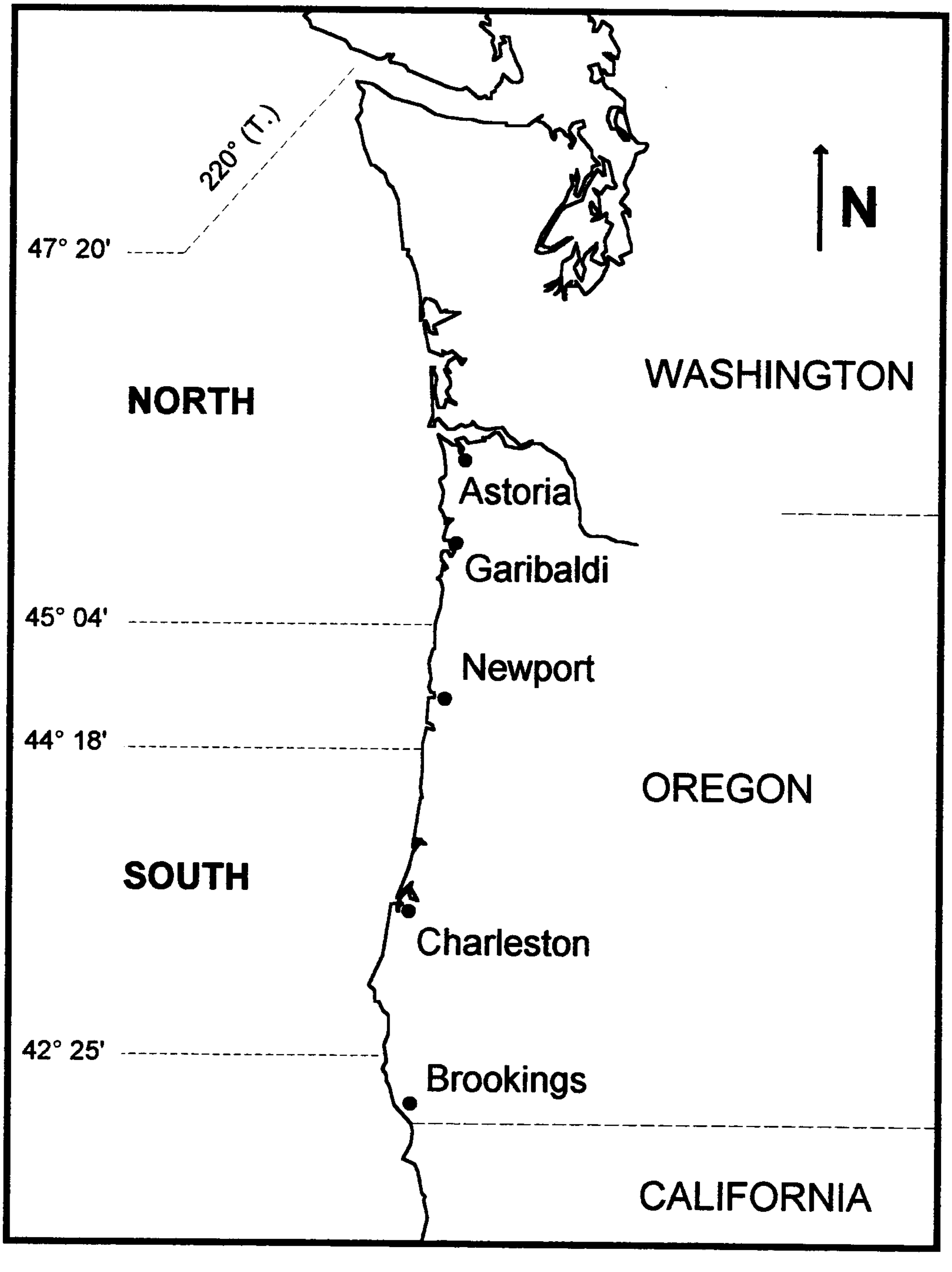

Figure 5.1. Study area used to conduct maturity assessment of Dover sole commercially landed at Oregon ports (1989 - 1991).

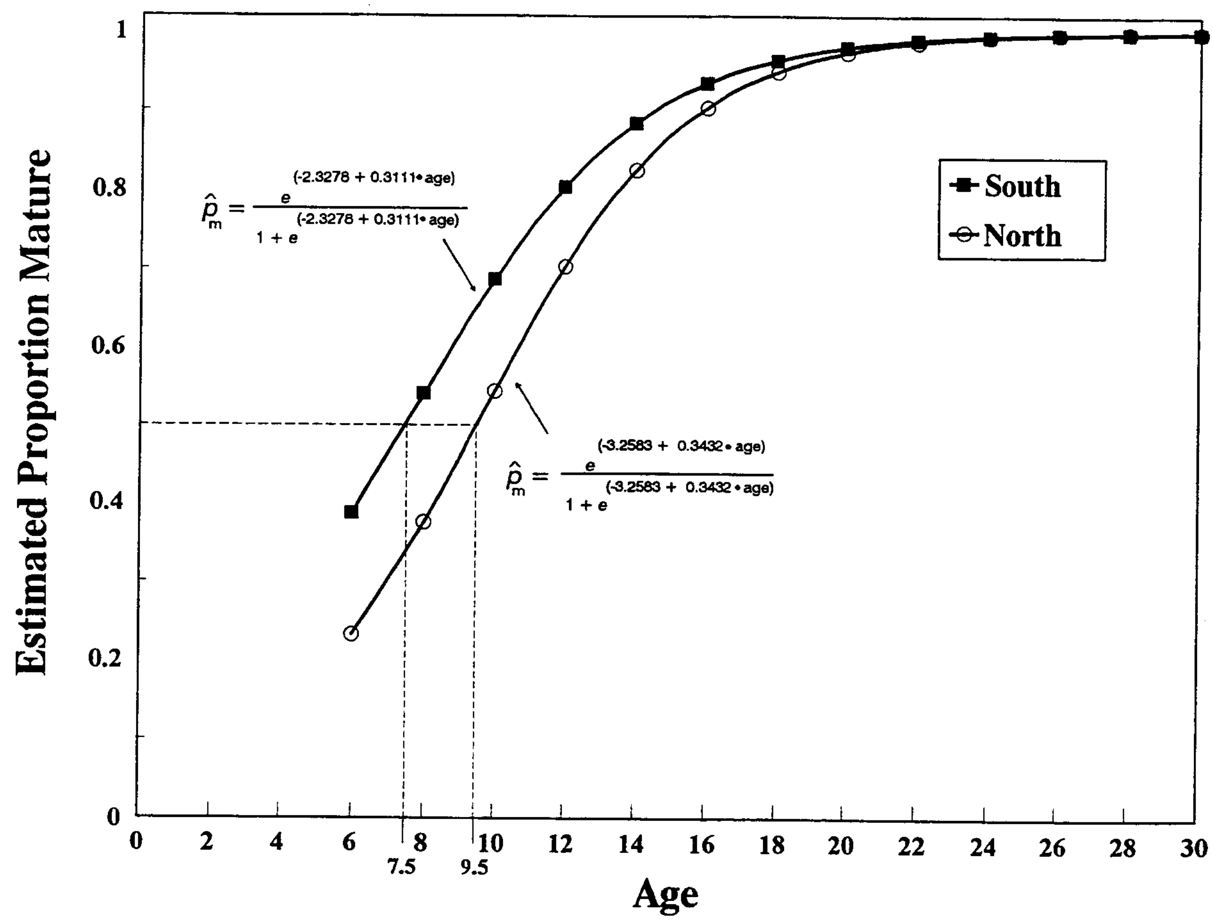

Figure 5.2. Logistic regression models and associated curves for estimated proportion ($\hat{p}_m$) of female Dover sole that were sexually mature as a function of age (yr). The maturity schedules of fish for the north and south regions of Oregon (1989 - 1991) are compared. Fish were sampled before the spawning period (Before time block).

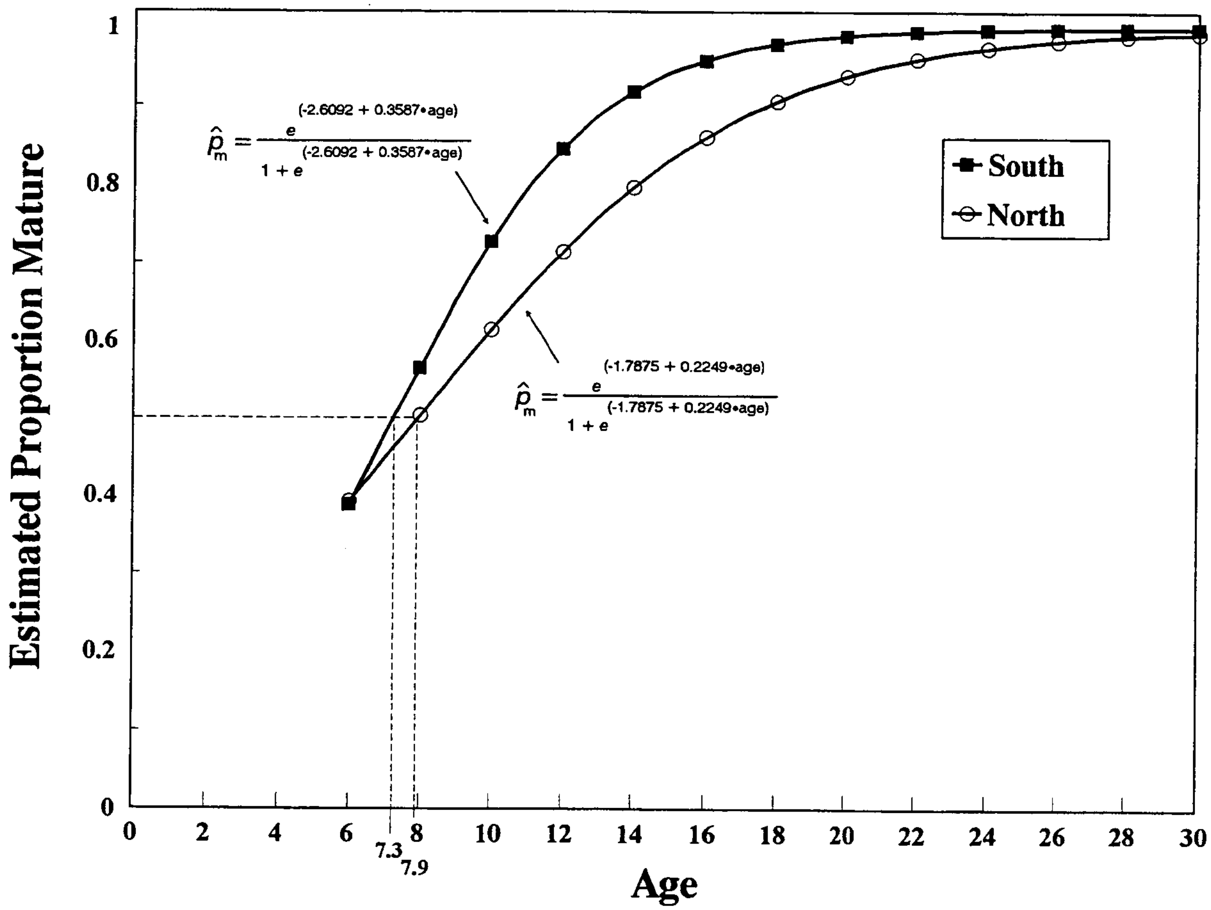

Figure 5.3. Logistic regression models and associated curves for estimated proportion ($\hat{p}_m$) of female Dover sole that were sexually mature as a function of age (yr). The maturity schedules of fish for the north and south regions of Oregon (1989 - 1991) are compared. Fish were sampled during the spawning period (During time block).

Table 5.2. Analysis of deviance table for logistic regression models and corresponding tests used in maturity assessment of female Dover sole in Oregon (1989 - 1991). Results are presented separately for two time blocks.

Time block [a]	Model	Deviance	*df* [b]	Test	Drop-in-deviance	*df*	*P* [c]
Before	age+region+age*region	838.71	492				
	age+region	838.93	493	age*region = 0	0.22	1	0.72
	age	848.75	494	region = age*region = 0	10.04	2	0.05
During	age+region+age*region	1,661.32	870				
	age+region	1,668.64	871	age*region = 0	7.32	1	0.05
	age	1,696.50	872	region = age*region = 0	35.18	2	<0.01

[a] Before denotes samples were collected before the spawning period while fish were not actively spawning and During denotes samples were collected during the spawning period while fish were actively spawning.

[b] Degrees of freedom (*df*) statistics were calculated from the total number of observations (ages) aggregated across boat trips. The estimated proportion of mature fish for each age included in a boat-trip sample was treated as an observation.

[c] Probability (*P*) values correspond to drop-in-deviance *F*-tests that included an additional dispersion parameter to account for extra-binomial variation.

Table 5.3. Results from logistic regression analyses of female Dover sole for the north and south regions of Oregon (1989 - 1991). Parameter estimates of maturity schedules are presented separately for two time blocks.

	Age at 50% mature[a] $Age_{50\%}$		Odds ratio[b]	
Time block[c]	North	South	North	South
Before	9.5	7.5	41% (25-57%)	37% (26-58%)
During	7.9	7.3	25% (18-31%)	43% (31-56%)

[a] Age (yr) at which there was a 50% probability that a fish was mature, $Age_{50\%}$, was estimated from the simple logistic response function of each region as, $-b_0 / b_1$, where b_0 was the estimated regression coefficient for the intercept and b_1 was the estimated regression coefficient for the explanatory variable age.

[b] The odds ratio is presented as the estimated percent increase in the odds of a fish being mature with each one-year increase in age. Confidence intervals (95%) for odds ratios are presented in parentheses. Odds ratios were estimated from the simple logistic response function of each region as, $\exp(b_1)$, where b_1 was the estimated regression coefficient for the explanatory variable age.

[c] Before denotes samples were collected before the spawning period while fish were not actively spawning and During denotes samples were collected during the spawning period while fish were actively spawning.

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APPENDICES

APPENDIX A

Table A.1. Common and scientific names for groundfish species (Robins et al. 1991).

Common name	Scientific name
Rougheye rockfish	*Sebastes aleutianus*
Pacific ocean perch	*Sebastes alutus*
Aurora rockfish	*Sebastes aurora*
Redbanded rockfish	*Sebastes babcocki*
Shortraker rockfish	*Sebastes borealis*
Silvergrey rockfish	*Sebastes brevispinus*
Greenspotted rockfish	*Sebastes chlorostictus*
Darkblotched rockfish	*Sebastes crameri*
Splitnose rockfish	*Sebastes diploproa*
Greenstriped rockfish	*Sebastes elongatus*
Widow rockfish	*Sebastes entomelas*
Yellowtail rockfish	*Sebastes flavidus*
Chilipepper	*Sebastes goodei*
Rosethorn rockfish	*Sebastes helvomaculatus*
Shortbelly rockfish	*Sebastes jordani*
Cowcod	*Sebastes levis*
Black rockfish	*Sebastes melanops*
Blackgill rockfish	*Sebastes melanostomus*
Tiger rockfish	*Sebastes nigrocinctus*
Speckled rockfish	*Sebastes ovalis*
Bocaccio	*Sebastes paucispinus*
Canary rockfish	*Sebastes pinniger*
Redstripe rockfish	*Sebastes proriger*
Yellowmouth rockfish	*Sebastes reedi*
Yelloweye rockfish	*Sebastes ruberrimus*
Bank rockfish	*Sebastes rufus*
Stripetail rockfish	*Sebastes saxicola*
Pygmy rockfish	*Sebastes wilsoni*
Sharpchin rockfish	*Sebastes zacentrus*
Shortspine thornyhead	*Sebastolobus alascanus*
Longspine thornyhead	*Sebastolobus altivelis*
English sole	*Parophrys vetulus*
Dover sole	*Microstomus pacificus*
Pacific whiting	*Merluccius productus*

APPENDIX B

Table B.1. Species-composition estimates by port/quarter strata for the rockfish fishery of Oregon in 1989. Landing estimates are in pounds of fish. For each port/quarter stratum, species are listed in descending order according to percent contribution to stratum total landings. Results have been rounded to whole numbers.

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{T}_{R..}$)	Percent of stratum total landings	*CV* (%)
Astoria	1	52	Widow	1,721,131	51	1
			Yellowtail	477,883	14	3
			Shortspine thornyhead	257,209	8	3
			Pacific ocean perch	242,288	7	5
			Canary	192,338	6	38
			Darkblotched	104,358	3	35
			Rougheye	78,619	2	52
			Shortraker	58,637	2	30
			Yellowmouth	50,969	2	39
			Sharpchin	41,813	1	23
			Silvergrey	36,824	1	88
			Splitnose	28,841	1	45
			Yelloweye	24,397	1	43
			Redstripe	19,871	1	67
			Aurora	14,233	<1	61
			Redbanded	9,795	<1	36
			Bocaccio	6,701	<1	55
			Rosethorn	5,687	<1	72
			Greenstriped	3,619	<1	46
			Subtotal	3,375,213	100	
Astoria	2	83	Widow	942,597	22	1
			Yellowtail	904,242	21	2
			Pacific ocean perch	584,413	14	6
			Shortspine thornyhead	431,446	10	1
			Canary	333,854	8	18
			Darkblotched	244,669	6	23
			Sharpchin	148,584	4	25
			Redstripe	123,722	3	28
			Rougheye	119,991	3	34
			Shortraker	80,758	2	27
			Yelloweye	71,499	2	29
			Bocaccio	52,291	1	33
			Silvergrey	49,276	1	33
			Black	41,693	1	88
			Splitnose	41,142	1	45
			Yellowmouth	15,565	<1	42
			Aurora	14,376	<1	39
			Redbanded	13,911	<1	39

Table B.1. (*Continued*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Greenstriped	12,089	<1	39
			Rosethorn	3,138	<1	58
			Subtotal	4,229,256	100	
Astoria	3	93	Widow	1,142,336	25	1
			Yellowtail	911,299	20	1
			Pacific ocean perch	502,698	11	5
			Canary	498,002	11	23
			Darkblotched	266,088	6	31
			Shortspine thornyhead	257,558	6	1
			Sharpchin	153,110	3	26
			Black	151,867	3	83
			Redstripe	141,550	3	34
			Rougheye	107,714	2	36
			Silvergrey	88,801	2	29
			Yellowmouth	83,560	2	28
			Greenstriped	64,121	1	36
			Splitnose	61,517	1	29
			Bocaccio	44,173	1	28
			Yelloweye	43,857	1	38
			Redbanded	23,645	1	24
			Shortraker	15,812	<1	49
			Aurora	11,017	<1	52
			Rosethorn	3,348	<1	29
			Blackgill	865	<1	96
			Subtotal	4,572,938	100	
Astoria	4	35	Shortspine thornyhead	369,083	19	2
			Yellowtail	291,744	15	2
			Widow	279,996	14	2
			Canary	181,739	9	53
			Pacific ocean perch	159,894	8	13
			Darkblotched	154,158	8	29
			Yellowmouth	138,236	7	70
			Rougheye	96,258	5	48
			Shortraker	75,765	4	36
			Redstripe	55,847	3	73
			Silvergrey	48,602	2	40
			Sharpchin	28,351	1	36
			Bocaccio	21,143	1	43
			Yelloweye	14,187	1	48
			Splitnose	13,683	1	35
			Aurora	12,614	1	47
			Redbanded	11,563	1	48

Table B.1. *(Continued)*

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Greenstriped	8,358	<1	47
			Rosethorn	2,039	<1	79
			Bank	1,593	<1	89
			Blackgill	457	<1	103
			Subtotal	1,965,310	100	
Tillamook	2	4	Redstripe	92,850	30	9
			Sharpchin	79,618	26	12
			Bocaccio	25,175	8	90
			Yelloweye	24,925	8	35
			Rougheye	23,797	8	103
			Canary	17,484	6	56
			Pacific ocean perch	13,927	4	94
			Greenstriped	13,572	4	3
			Darkblotched	4,839	2	92
			Widow	3,137	1	82
			Yellowtail	3,005	1	95
			Splitnose	2,889	1	102
			Redbanded	2,555	1	19
			Yellowmouth	1,539	<1	91
			Silvergrey	1,320	<1	90
			Aurora	1,293	<1	92
			Rosethorn	113	<1	178
			Subtotal	312,038	100	
Newport	1	85	Widow	5,574,939	80	1
			Canary	419,235	6	10
			Darkblotched	278,281	4	13
			Yellowtail	177,392	3	7
			Pacific ocean perch	172,880	2	19
			Shortspine thornyhead	97,198	1	1
			Bocaccio	55,800	1	55
			Yellowmouth	48,725	1	47
			Silvergrey	34,303	<1	42
			Redstripe	28,764	<1	41
			Splitnose	26,454	<1	48
			Shortraker	19,501	<1	83
			Yelloweye	12,985	<1	44
			Sharpchin	10,518	<1	61
			Redbanded	6,375	<1	58
			Rougheye	3,120	<1	67
			Aurora	3,045	<1	52
			Bank	2,122	<1	54
			Greenstriped	2,076	<1	38

Table B.1. (*Continued*)

Port	Quarter	n	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	CV (%)
			Rosethorn	67	<1	100
			Shortbelly	7	<1	103
			Subtotal	6,973,787	100	
Newport	2	32	Widow	1,478,857	67	1
			Canary	312,854	14	9
			Yellowtail	138,300	6	13
			Pacific ocean perch	64,004	3	7
			Darkblotched	60,778	3	16
			Silvergrey	44,689	2	18
			Yellowmouth	37,738	2	23
			Splitnose	17,375	1	41
			Rougheye	16,123	1	85
			Bocaccio	11,800	1	65
			Redbanded	9,307	<1	44
			Yelloweye	7,552	<1	50
			Redstripe	5,757	<1	95
			Bank	4,314	<1	58
			Sharpchin	2,863	<1	49
			Greenstriped	1,233	<1	43
			Greenspotted	148	<1	93
			Subtotal	2,213,692	100	
Newport	3	55	Widow	1,340,642	47	1
			Canary	409,351	14	21
			Yellowmouth	257,819	9	42
			Yellowtail	157,666	6	12
			Bocaccio	134,041	5	24
			Silvergrey	114,685	4	37
			Shortspine thornyhead	102,287	4	1
			Pacific ocean perch	101,333	4	10
			Yelloweye	83,496	3	37
			Redstripe	56,770	2	48
			Darkblotched	47,559	2	45
			Sharpchin	18,178	1	46
			Greenstriped	17,798	1	96
			Splitnose	5,332	<1	54
			Greenspotted	1,964	<1	91
			Redbanded	1,940	<1	57
			Bank	1,166	<1	74
			Shortraker	342	<1	116
			Shortbelly	52	<1	74

Table B.1. (*Continued*)

Port	Quarter	n	Rockfish species	Landing estimate $(\hat{T}_{R..})$	Percent of stratum total landings	CV (%)
			Aurora	34	<1	116
			Rosethorn	6	<1	116
			Subtotal	2,852,461	100	
Newport	4	30	Canary	303,965	29	39
			Widow	250,896	24	1
			Shortspine thornyhead	109,284	11	1
			Yellowtail	93,813	9	53
			Darkblotched	56,788	5	54
			Rougheye	37,658	4	101
			Bocaccio	34,296	3	33
			Yelloweye	28,455	3	50
			Sharpchin	25,578	2	77
			Yellowmouth	25,280	2	56
			Pacific ocean perch	24,616	2	20
			Shortraker	18,104	2	79
			Redstripe	12,302	1	67
			Silvergrey	6,008	1	75
			Splitnose	5,963	1	61
			Aurora	1,838	<1	60
			Bank	1,661	<1	78
			Greenstriped	1,010	<1	101
			Redbanded	766	<1	71
			Subtotal	1,038,281	100	
Coos Bay	1	24	Widow	783,042	41	1
			Shortspine thornyhead	263,848	14	21
			Longspine thornyhead	256,480	14	22
			Darkblotched	178,628	9	49
			Canary	103,521	5	38
			Yellowtail	85,791	5	56
			Bocaccio	44,290	2	53
			Splitnose	44,038	2	38
			Sharpchin	28,102	1	29
			Redstripe	16,139	1	55
			Greenstriped	15,792	1	100
			Yellowmouth	15,106	1	81
			Yelloweye	14,081	1	37
			Pacific ocean perch	10,984	1	41
			Cowcod	9,020	<1	101
			Rougheye	7,591	<1	75
			Aurora	4,800	<1	57
			Shortbelly	4,537	<1	27
			Silvergrey	2,683	<1	101

Table B.1. (*Continued*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{T}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Redbanded	2,516	<1	36
			Rosethorn	1,363	<1	47
			Blackgill	1,295	<1	81
			Bank	1,005	<1	72
			Greenspotted	518	<1	60
			Shortraker	426	<1	113
			Pygmy	87	<1	108
			Subtotal	1,895,683	100	
Coos Bay	2	47	Shortspine thornyhead	157,299	15	15
			Yellowtail	134,062	13	14
			Widow	130,106	12	4
			Yellowmouth	114,578	11	30
			Canary	97,954	9	35
			Longspine thornyhead	95,836	9	24
			Darkblotched	94,469	9	32
			Pacific ocean perch	77,404	7	23
			Rougheye	25,861	2	40
			Bocaccio	24,160	2	46
			Redstripe	23,923	2	64
			Aurora	19,467	2	66
			Splitnose	19,345	2	44
			Sharpchin	10,858	1	66
			Yelloweye	10,258	1	46
			Greenstriped	7,750	1	50
			Silvergrey	6,013	1	55
			Redbanded	2,785	<1	61
			Rosethorn	1,073	<1	80
			Greenspotted	999	<1	51
			Bank	286	<1	98
			Pygmy	24	<1	100
			Subtotal	1,054,510	100	
Coos Bay	3	54	Shortspine thornyhead	365,807	23	11
			Widow	364,490	23	2
			Longspine thornyhead	243,792	15	17
			Yellowtail	120,193	8	20
			Canary	79,376	5	56
			Yellowmouth	66,660	4	47
			Splitnose	65,545	4	47
			Darkblotched	63,978	4	39
			Bocaccio	45,993	3	39
			Greenstriped	32,797	2	38
			Pacific ocean perch	31,570	2	19

Table B.1. (*Continued*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Rougheye	31,288	2	54
			Sharpchin	17,077	1	43
			Yelloweye	16,159	1	36
			Redstripe	14,294	1	58
			Shortraker	10,604	1	85
			Greenspotted	5,890	<1	64
			Aurora	5,536	<1	52
			Chilipepper	4,929	<1	91
			Redbanded	3,761	<1	44
			Silvergrey	3,734	<1	57
			Rosethorn	1,955	<1	41
			Stripetail	484	<1	66
			Shortbelly	239	<1	96
			Subtotal	1,596,151	100	
Coos Bay	4	15	Longspine thornyhead	460,435	38	5
			Darkblotched	259,140	21	17
			Shortspine thornyhead	193,317	16	12
			Widow	95,284	8	1
			Pacific ocean perch	69,870	6	15
			Rougheye	49,319	4	39
			Sharpchin	21,940	2	69
			Yellowmouth	16,631	1	55
			Aurora	12,091	1	49
			Redstripe	10,035	1	49
			Yellowtail	9,038	1	55
			Bocaccio	3,928	<1	123
			Splitnose	3,913	<1	75
			Redbanded	3,799	<1	90
			Greenspotted	3,796	<1	55
			Greenstriped	1,234	<1	50
			Chilipepper	1,088	<1	114
			Bank	863	<1	114
			Pygmy	113	<1	114
			Subtotal	1,215,834	100	
Brookings	1	8	Widow	337,570	47	1
			Shortspine thornyhead	193,243	27	34
			Longspine thornyhead	157,668	22	42
			Redstripe	26,778	4	9
			Shortbelly	3,133	<1	81
			Sharpchin	1,355	<1	59
			Greenstriped	84	<1	111
			Subtotal	719,831	100	

Table B.1. (*Concluded*)

Port	Quarter	n	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	CV (%)
Brookings	2	15	Shortspine thornyhead	283,527	29	8
			Widow	275,888	29	1
			Longspine thornyhead	234,043	24	10
			Yellowtail	91,365	9	1
			Canary	51,649	5	27
			Greenstriped	11,474	1	27
			Greenspotted	5,003	1	151
			Darkblotched	2,712	<1	102
			Bocaccio	2,497	<1	8
			Yelloweye	2,256	<1	151
			Splitnose	603	<1	65
			Pacific ocean perch	540	<1	114
			Sharpchin	455	<1	63
			Redbanded	444	<1	120
			Rosethorn	303	<1	103
			Chilipepper	180	<1	151
			Redstripe	131	<1	151
			Subtotal	963,070	100	
Brookings	3	12	Longspine thornyhead	321,270	39	29
			Widow	278,198	34	1
			Shortspine thornyhead	161,779	20	58
			Canary	22,142	3	16
			Greenstriped	8,275	1	31
			Splitnose	6,311	1	27
			Yellowtail	5,899	1	75
			Darkblotched	4,760	1	68
			Redbanded	2,614	<1	59
			Sharpchin	1,691	<1	41
			Silvergrey	1,147	<1	63
			Pacific ocean perch	1,069	<1	33
			Bocaccio	1,063	<1	107
			Greenspotted	769	<1	63
			Chilipepper	592	<1	58
			Yelloweye	580	<1	14
			Rosethorn	251	<1	37
			Rougheye	242	<1	58
			Redstripe	62	<1	111
			Pygmy	8	<1	106
			Subtotal	818,722	100	
			Total	35,796,777		

Table B.2. Species-composition estimates for the rockfish fishery of Oregon in 1989. Landing estimates are in pounds of fish. Species are listed in descending order according to percent contribution to coastwide total landings. Results have been rounded to whole numbers. n = 644.[a]

Rockfish species	Landing estimate	Percent of coastwide total landings	*CV* (%)
Widow	14,999,110	42	1
Yellowtail	3,601,692	10	2
Shortspine thornyhead	3,242,884	9	4
Canary	3,023,464	8	8
Pacific ocean perch	2,057,490	6	3
Darkblotched	1,821,205	5	9
Longspine thornyhead	1,769,524	5	8
Yellowmouth	872,406	2	18
Redstripe	628,794	2	13
Rougheye	597,580	2	17
Sharpchin	590,088	2	11
Bocaccio	507,351	1	13
Silvergrey	438,083	1	15
Yelloweye	354,689	1	13
Splitnose	342,953	1	14
Shortraker	279,950	1	17
Greenstriped	201,282	1	18
Black	193,561	<1	68
Aurora	100,343	<1	20
Redbanded	95,777	<1	13
Rosethorn	19,343	<1	26
Greenspotted	19,086	<1	47
Bank	13,011	<1	28
Cowcod	9,020	<1	101
Shortbelly	7,967	<1	36
Chilipepper	6,789	<1	69
Blackgill	2,617	<1	54
Stripetail	484	<1	66
Pygmy	232	<1	70
Total	35,796,775	100	

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[a] Only market categories with n_j >1, within a port/quarter stratum, were included in analyses that generated coastwide landing estimates for 1989—these samples were used to evaluate approximately 94% of the total landings.

Table B.3. Species-composition estimates by port/quarter strata for the rockfish fishery of Oregon in 1990. Landing estimates are in pounds of fish. For each port/quarter stratum, species are listed in descending order according to percent contribution to stratum total landings. Results have been rounded to whole numbers.

Port	Quarter	n	Rockfish species	Landing estimate $(\hat{T}_{R..})$	Percent of stratum total landings	CV (%)
Astoria	1	65	Widow	1,083,017	36	1
			Yellowtail	697,143	23	1
			Shortspine thornyhead	262,553	9	1
			Pacific ocean perch	204,472	7	3
			Canary	164,486	5	44
			Darkblotched	118,813	4	40
			Rougheye	105,787	4	36
			Redstripe	83,295	3	39
			Shortraker	59,314	2	50
			Silvergrey	57,014	2	54
			Yellowmouth	49,016	2	36
			Sharpchin	45,586	2	29
			Splitnose	20,734	1	43
			Aurora	16,814	1	22
			Yelloweye	10,073	<1	42
			Greenstriped	9,528	<1	45
			Redbanded	9,439	<1	48
			Greenspotted	6,137	<1	66
			Bocaccio	4,722	<1	61
			Blackgill	2,711	<1	85
			Rosethorn	2,632	<1	37
			Subtotal	3,013,286	100	
Astoria	2	81	Yellowtail	859,962	28	1
			Widow	776,043	25	1
			Canary	406,544	13	20
			Shortspine thornyhead	288,326	9	1
			Pacific ocean perch	204,733	7	3
			Darkblotched	121,458	4	47
			Silvergrey	120,514	4	36
			Shortraker	87,312	3	37
			Bocaccio	70,682	2	52
			Redstripe	28,694	1	41
			Splitnose	18,105	1	39
			Sharpchin	17,845	1	31
			Yelloweye	16,013	1	43
			Rougheye	14,239	<1	32
			Yellowmouth	10,067	<1	36
			Greenstriped	7,859	<1	56
			Aurora	7,553	<1	29

Table B.3. (*Continued*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Redbanded	2,735	<1	70
			Rosethorn	1,304	<1	40
			Stripetail	103	<1	100
			Blackgill	69	<1	100
			Subtotal	3,060,160	100	
Astoria	3	84	Widow	1,324,189	36	1
			Yellowtail	570,972	16	1
			Pacific ocean perch	324,205	9	3
			Canary	298,421	8	17
			Longspine thornyhead	278,688	8	13
			Shortspine thornyhead	165,220	5	22
			Silvergrey	141,751	4	21
			Redstripe	102,592	3	22
			Bocaccio	89,583	2	27
			Shortraker	75,308	2	30
			Darkblotched	61,775	2	29
			Rougheye	43,755	1	28
			Black	42,678	1	78
			Sharpchin	30,549	1	31
			Splitnose	20,656	1	34
			Redbanded	20,400	1	36
			Yelloweye	13,877	<1	35
			Aurora	10,757	<1	74
			Yellowmouth	9,539	<1	33
			Greenstriped	9,209	<1	44
			Rosethorn	748	<1	53
			Tiger	586	<1	94
			Subtotal	3,635,458	100	
Astoria	4	33	Widow	685,776	42	1
			Shortspine thornyhead	158,183	10	30
			Yellowtail	139,202	8	1
			Pacific ocean perch	138,940	8	1
			Canary	110,414	7	32
			Longspine thornyhead	69,983	4	68
			Yellowmouth	67,132	4	32
			Rougheye	65,630	4	41
			Darkblotched	53,477	3	32
			Bocaccio	37,881	2	59
			Silvergrey	33,410	2	69
			Sharpchin	22,417	1	32
			Aurora	15,792	1	32
			Shortraker	14,324	1	63

Table B.3. (*Continued*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{T}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Splitnose	8,182	<1	78
			Redstripe	7,943	<1	48
			Redbanded	4,329	<1	86
			Yelloweye	4,221	<1	79
			Greenstriped	3,097	<1	50
			Bank	2,167	<1	71
			Rosethorn	444	<1	80
			Chilipepper	108	<1	105
			Subtotal	1,643,052	100	
Tillamook	1	12	Widow	153,725	41	1
			Redstripe	107,342	29	3
			Sharpchin	23,657	6	22
			Canary	17,870	5	45
			Rougheye	16,729	4	44
			Greenstriped	10,683	3	16
			Shortraker	8,338	2	84
			Silvergrey	6,865	2	58
			Yellowmouth	6,616	2	57
			Pacific ocean perch	5,595	1	71
			Yelloweye	5,227	1	52
			Bocaccio	3,510	1	49
			Darkblotched	1,899	1	48
			Redbanded	1,600	<1	52
			Splitnose	1,170	<1	97
			Blackgill	1,169	<1	84
			Aurora	1,040	<1	66
			Yellowtail	428	<1	95
			Rosethorn	413	<1	53
			Shortspine thornyhead	115	<1	110
			Subtotal	373,991	100	
Tillamook	2	14	Widow	103,697	41	1
			Yellowmouth	33,642	13	29
			Redstripe	22,873	9	11
			Silvergrey	21,040	8	40
			Sharpchin	19,087	8	6
			Shortspine thornyhead	14,798	6	6
			Pacific ocean perch	11,409	5	61
			Canary	5,677	2	69
			Darkblotched	3,712	1	20
			Greenstriped	3,681	1	3
			Redbanded	2,600	1	30
			Rougheye	2,511	1	71

Table B.3. (*Continued*)

Port	Quarter	n	Rockfish species	Landing estimate $(\hat{Y}_{R..})$	Percent of stratum total landings	CV (%)
			Shortraker	1,504	1	65
			Aurora	1,419	1	5
			Splitnose	1,388	1	63
			Yelloweye	1,318	1	64
			Longspine thornyhead	952	<1	114
			Bocaccio	549	<1	79
			Rosethorn	396	<1	17
			Yellowtail	88	<1	99
			Subtotal	252,341	100	
Tillamook	3	4	Redstripe	98,287	57	2
			Sharpchin	18,476	11	27
			Canary	17,511	10	59
			Yellowmouth	12,401	7	60
			Greenstriped	11,006	6	28
			Silvergrey	4,237	2	38
			Bocaccio	2,979	2	65
			Yelloweye	2,860	2	8
			Redbanded	1,172	1	129
			Pacific ocean perch	1,057	1	65
			Darkblotched	834	<1	49
			Widow	293	<1	129
			Rougheye	110	<1	129
			Subtotal	171,223	100	
Newport	1	122	Widow	2,236,127	56	1
			Darkblotched	616,939	15	9
			Yellowtail	284,422	7	1
			Yellowmouth	189,010	5	18
			Shortspine thornyhead	188,315	5	1
			Pacific ocean perch	168,066	4	7
			Canary	92,966	2	28
			Rougheye	57,208	1	58
			Yelloweye	37,552	1	25
			Bocaccio	36,244	1	32
			Redstripe	30,074	1	38
			Silvergrey	24,304	1	27
			Splitnose	23,270	1	23
			Sharpchin	19,312	<1	28
			Shortraker	4,497	<1	86
			Redbanded	4,092	<1	44
			Bank	3,162	<1	52
			Aurora	2,755	<1	30
			Greenstriped	1,927	<1	29

Table B.3. (*Continued*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Blackgill	678	<1	85
			Rosethorn	232	<1	49
			Subtotal	4,021,152	100	
Newport	2	8	Widow	468,779	78	1
			Canary	129,493	22	1
			Subtotal	598,272	100	
Newport	3	55	Widow	1,618,259	62	1
			Shortspine thornyhead	342,644	13	19
			Canary	140,980	5	10
			Darkblotched	138,205	5	13
			Longspine thornyhead	85,474	3	76
			Yellowtail	83,397	3	4
			Yellowmouth	68,727	3	28
			Pacific ocean perch	56,065	2	10
			Splitnose	38,852	1	29
			Rougheye	19,354	1	56
			Aurora	6,797	<1	87
			Sharpchin	5,891	<1	65
			Bank	5,350	<1	77
			Redbanded	3,192	<1	88
			Bocaccio	3,004	<1	78
			Redstripe	2,679	<1	75
			Shortraker	2,585	<1	112
			Greenstriped	2,118	<1	83
			Rosethorn	755	<1	41
			Greenspotted	345	<1	109
			Subtotal	2,624,673	100	
Newport	4	37	Widow	1,263,725	72	1
			Canary	136,102	8	18
			Darkblotched	115,626	7	19
			Yellowtail	70,213	4	6
			Yellowmouth	68,769	4	25
			Bocaccio	37,806	2	20
			Yelloweye	14,354	1	33
			Pacific ocean perch	11,356	1	59
			Redbanded	8,669	<1	53
			Splitnose	7,071	<1	29
			Greenstriped	6,533	<1	100
			Silvergrey	5,997	<1	62
			Rougheye	5,030	<1	67
			Sharpchin	3,489	<1	9

Table B.3. (*Continued*)

Port	Quarter	n	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	CV (%)
			Bank	2,033	<1	76
			Aurora	1,459	<1	84
			Redstripe	1,431	<1	66
			Subtotal	1,759,663	100	
Coos Bay	1	27	Longspine thornyhead	1,643,525	58	7
			Widow	581,632	21	1
			Shortspine thornyhead	175,910	6	67
			Darkblotched	171,168	6	26
			Yellowtail	113,020	4	3
			Redstripe	52,504	2	35
			Canary	30,766	1	74
			Greenstriped	21,929	1	88
			Silvergrey	7,426	<1	113
			Yelloweye	6,940	<1	107
			Sharpchin	6,296	<1	38
			Splitnose	6,123	<1	33
			Bocaccio	5,496	<1	90
			Pacific ocean perch	5,307	<1	24
			Rosethorn	1,898	<1	31
			Yellowmouth	1,463	<1	95
			Rougheye	768	<1	109
			Greenspotted	687	<1	84
			Aurora	532	<1	108
			Shortbelly	324	<1	117
			Redbanded	184	<1	81
			Stripetail	174	<1	114
			Shortraker	62	<1	133
			Subtotal	2,834,134	100	
Coos Bay	2	40	Longspine thornyhead	780,407	42	18
			Shortspine thornyhead	546,004	30	26
			Widow	151,684	8	1
			Canary	101,522	6	48
			Redstripe	67,019	4	32
			Yellowmouth	64,027	3	57
			Darkblotched	38,215	2	46
			Yellowtail	26,707	1	3
			Bocaccio	15,513	1	69
			Rougheye	10,101	1	76
			Pacific ocean perch	10,081	1	49
			Greenstriped	9,820	1	25
			Splitnose	8,517	<1	72
			Yelloweye	7,018	<1	80

Table B.3. (*Continued*)

Port	Quarter	n	Rockfish species	Landing estimate ($\hat{Y}_{R..}$)	Percent of stratum total landings	CV (%)
			Redbanded	4,468	<1	56
			Aurora	507	<1	98
			Bank	138	<1	113
			Pygmy	133	<1	69
			Sharpchin	125	<1	71
			Blackgill	62	<1	114
			Shortbelly	24	<1	104
			Subtotal	1,842,092	100	
Coos Bay	3	41	Longspine thornyhead	1,379,264	45	6
			Shortspine thornyhead	533,342	17	17
			Widow	466,848	15	3
			Canary	345,012	11	22
			Yellowtail	122,778	4	37
			Redstripe	85,965	3	26
			Bocaccio	67,990	2	40
			Splitnose	22,786	1	78
			Yelloweye	19,274	1	44
			Redbanded	12,187	<1	50
			Rougheye	11,782	<1	79
			Darkblotched	11,437	<1	68
			Pacific ocean perch	8,302	<1	70
			Greenstriped	8,139	<1	47
			Chilipepper	513	<1	101
			Subtotal	3,095,619	100	
Coos Bay	4	25	Longspine thornyhead	597,509	24	16
			Widow	505,398	20	1
			Canary	445,651	18	15
			Shortspine thornyhead	417,231	17	22
			Yellowtail	285,479	11	12
			Darkblotched	99,639	4	45
			Bocaccio	82,454	3	13
			Yelloweye	25,008	1	107
			Redstripe	23,372	1	87
			Sharpchin	20,672	1	37
			Chilipepper	6,343	<1	54
			Redbanded	4,010	<1	111
			Pacific ocean perch	3,880	<1	54
			Rougheye	2,801	<1	107
			Bank	2,180	<1	53
			Splitnose	1,744	<1	60
			Greenstriped	850	<1	80
			Black	711	<1	136

Table B.3. (*Concluded*)

Port	Quarter	*n*	Rockfish species	Landing estimate ($\hat{T}_{R..}$)	Percent of stratum total landings	*CV* (%)
			Aurora	375	<1	112
			Rosethorn	146	<1	140
			Subtotal	2,525,453	100	
Brookings	1	2	Bocaccio	9,262	48	42
			Canary	4,903	26	2
			Splitnose	1,452	8	137
			Shortraker	882	5	50
			Widow	604	3	137
			Silvergrey	455	2	50
			Greenspotted	365	2	137
			Greenstriped	336	2	137
			Yellowtail	258	1	137
			Redbanded	190	1	137
			Rougheye	185	1	137
			Aurora	174	1	50
			Rosethorn	54	<1	137
			Subtotal	19,120	100	
Brookings	3	6	Widow	373,905	43	1
			Longspine thornyhead	241,407	28	2
			Shortspine thornyhead	207,321	24	2
			Splitnose	13,758	2	53
			Sharpchin	13,336	2	90
			Greenstriped	5,194	1	47
			Redstripe	1,382	<1	100
			Greenspotted	825	<1	96
			Rosethorn	814	<1	15
			Darkblotched	729	<1	100
			Pacific ocean perch	707	<1	96
			Redbanded	354	<1	96
			Subtotal	859,732	100	
Brookings	4	3	Longspine thornyhead	217,712	73	9
			Shortspine thornyhead	81,994	27	24
			Subtotal	299,706	100	
			Total	32,629,127		

Table B.4. Species-composition estimates for the rockfish fishery of Oregon in 1990. Landing estimates are in pounds of fish. Species are listed in descending order according to percent contribution to coastwide total landings. Results have been rounded to whole numbers. n = 659.[a]

Rockfish species	Landing estimate	Percent of coastwide total landings	*CV* (%)
Widow	11,793,702	36	1
Longspine thornyhead	5,294,921	16	5
Shortspine thornyhead	3,381,955	10	7
Yellowtail	3,254,068	10	2
Canary	2,448,318	8	7
Darkblotched	1,553,927	5	8
Pacific ocean perch	1,154,172	4	2
Redstripe	715,452	2	8
Yellowmouth	580,408	2	11
Bocaccio	467,675	1	13
Silvergrey	423,012	1	16
Rougheye	355,988	1	17
Shortraker	254,127	1	20
Sharpchin	246,738	1	10
Splitnose	193,808	1	15
Yelloweye	163,736	1	20
Greenstriped	111,909	<1	20
Redbanded	79,622	<1	17
Aurora	65,972	<1	18
Black	43,390	<1	77
Bank	15,029	<1	34
Rosethorn	9,836	<1	15
Greenspotted	8,359	<1	51
Chilipepper	6,964	<1	49
Blackgill	4,690	<1	55
Tiger	587	<1	94
Shortbelly	350	<1	109
Stripetail	278	<1	81
Pygmy	134	<1	69
Total	32,629,127	100	

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[a] Only market categories with n_j >1, within a port/quarter stratum, were included in analyses that generated coastwide landing estimates for 1990—these samples were used to evaluate approximately 93% of the total landings.