Sampling design and statistical considerations for the commercial groundfish fishery of Oregon

Paul R. Crone

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 used 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. At least two-thirds of the total amount of rockfish landed in each port/quarter stratum consisted of estimates of species composition that had small coefficients of variation (CV <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 estimates for the species and age compositions, respectively.

Résumé : La gestion des ressources halieutiques s'appuie souvent sur les données recueillies par divers programmes d'inventaires. Il convient, au minimum, de contrôler les prises commerciales au débarquement afin d'en déterminer la composition (espèces et classes d'âge) aux fins de l'évaluation des stocks. Un autre objectif important, mais souvent ignoré, consiste à déterminer la variabilité des estimations ainsi obtenues. Le présent article expose des mesures de la dispersion des estimations obtenues à l'aide d'un protocole d'échantillonnage à deux volets utilisé pour les prises commerciales de poissons de fond débarquées dans les ports de l'Oregon. On s'attache en particulier à déterminer l'amplitude relative de la variabilité à la première et à la seconde étape de l'échantillonnage destiné à fournir une estimation de la composition par espèces et par groupes d'âge. Les deux tiers au moins du volume total de sébastes débarqués pour chaque tranche « port/trimestre » présentait des compositions par espèces estimatives assorties de petits coefficients de variation (CV < 10%). Pour chaque espèce dont on a déterminé la répartition par classes d'âge, les trois quarts au moins du total des débarquements incluaient des estimations de l'âge de spécimens individuels dont le CV était inférieur à 25%. Pour la majorité des débarquements, les variations intervenues lors de la première étape de l'échantillonnage étaient rèsponsables d'au moins 63 et 90% de la variance des estimations de la composition par espèces et par groupes d'âge respectivement.
[Traduit par la Rédaction]

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 constituted the population.

Received July 30, 1993. Accepted October 4, 1994.
J12028

P.R. Crone. Department of Fisheries and Wildlife, 104 Nash Hall, Oregon State University, Corvallis, OR 97331, U.S.A.

Popular stock assessment models, such as virtual population analysis (Gulland 1965), cohort analysis (Pope 1983), 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 designs 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 among primary units (boat trips) versus variability among 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 among boat trips. The common and scientific names for the species of groundfish discussed in this paper are presented in Table 1.

Table 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*

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 (*i*) species compositions of the market categories or (*ii*) 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 3-month blocks) combinations were treated as strata and boat trips within a stratum as primary units; primary 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 units) of a fixed weight were subsampled within each market category; the secondary 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: Astoria, Newport, and 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: (*i*) widow rockfish (WDW), (*ii*) yellowtail rockfish (YWT), (*iii*) Pacific ocean perch (POP), (*iv*) thornyhead (TYH), (*v*) large rockfish complex (LRC), and (*vi*) 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 t of the category landed. That is, each sample consisted of two to six baskets of fish (secondary units) selected from a market category (poststratification unit) within a boat trip (primary unit). Sampling protocols required at the second stage of the design were as follows: (*i*) two to four 11.34-kg (25 lb) baskets were taken for the WDW and TYH market categories; (*ii*) two to four 22.68-kg (50 lb) baskets were selected for the YWT and POP market categories; (*iii*) four to six 11.34-kg baskets were chosen for the SRC market category; and (*iv*) 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 t 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 baskets were selected, and for yellowtail rockfish and canary rockfish, 22.68-kg 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. All notation and formulae used to derive landing statistics presented here are given in the Appendix.

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 the 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).

Results

Results are presented separately for the species- and age-composition sampling programs. Estimates of species composition are presented as weight (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 the fourth quarter (October–December) 1991 and first 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 in the first 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 constituted 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). 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); 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). The CV of the landing estimates were fairly large (22–35%) 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). The estimates for thornyhead species 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 their own species, namely Pacific ocean perch, yellowtail rockfish, and widow rockfish, for the three market categories, respectively (Table 2). The landing estimates for these species within their respective market categories were very precise, with CVs always ≤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 among 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 (Fig. 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

Table 2. Species-composition summaries by market category for rockfish landings in Oregon, October 1991 – March 1992. Ranges for landing estimates (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 ($\hat{Y}_{.j}$)	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
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

Table 2 (*concluded*).

Market category[b]	Rockfish species	Range[a]: Landing estimate ($\hat{Y}_{.j}$)	Percent of market-category total landings	CV (%)
WDW	Widow	40 064 – 516 605	99–100	0–1
	Miscellaneous[d]	581 – 2 459	<1	60–102

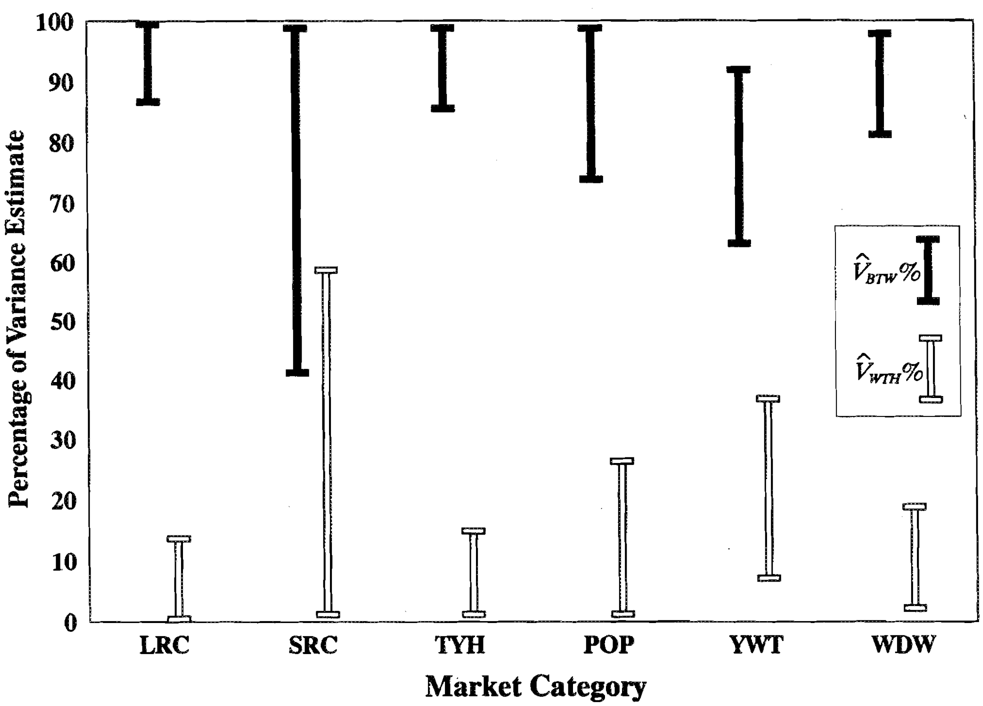
[a]Ranges for landing estimates and percent of market-category total landings that include zero indicate the rockfish species was not landed in the noted market category of all six strata. Ranges for CV are based on market categories of strata that rockfish species were landed in.

[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.

Fig. 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.



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 3). 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

Table 3. Species-composition summary for total rockfish landings in Oregon, October 1991 – March 1992. Ranges for landing estimates (kg), percent of stratum total landings, and CV are based on species-composition results for six port/quarter strata. Rockfish species are listed in descending order according to maximum percent contribution to stratum total landings.

	Range[a]		
Rockfish species	Landing estimate ($\hat{Y}_{..}$)	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[b]	15 – 10 685	<1	27–121

Note: Stratum landing estimates for rockfish species were calculated by simply summing market-category estimates within strata (see Estimation procedures and Appendix).

[a]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.

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

121% (Table 3), 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 3).

The estimates for Newport in the first quarter of 1992 (Table 4) were typical of the general characteristics of species composition presented above (Tables 2 and 3, Fig. 1). The LRC and SRC market categories consisted primarily of species that were 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 species, Pacific ocean perch, yellowtail rockfish, and widow rockfish, for the four market categories, respectively (Table 4). 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 Newport in the first quarter of 1992, 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 among boat trips, $\hat{V}_{\mathrm{BTW}}$ %, (Table 4). 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 $\hat{V}_{\mathrm{BTW}}$ %; however, the remaining 30% of the species composition included landing estimates with variances that incorporated considerable amounts of second-stage sampling error ($\hat{V}_{\mathrm{WTH}}$ %).

Approximately 90% of the total landings for Newport in the first quarter of 1992 included species that had precise landing estimates, with CVs ≤12% (Table 5). With the exception of canary rockfish, which was primarily landed in the LRC market category (Table 4), 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 6). 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 4–11% 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 among 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 V_{BTW} %.

Estimates of age composition for yellowtail rockfish landed at Oregon ports in 1991 were typical of the general age-composition results (Table 7). 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 ≤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 much 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), Oregon State University, Hatfield Marine Science Center, Newport, OR 97365, 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 many 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 the design. 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 variation among boat trips ($\hat{V}_{BTW}$ %) and very little variation existed among 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, given the technical difficulties and additional time involved in 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

Table 4. Species-composition estimates by market category for the Newport/first 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 ($\hat{Y}_{.j}$)	Percent of market-category total landings	$\hat{V}_{BTW}$ %	$\hat{V}_{WTH}$ %	CV (%)
LRC						
(n_j = 13)[b]	Canary	103 264	52	94	6	12
	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						
(n_j = 13)	Darkblotched	20 241	38	97	3	22
	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			
TYH						
(n_j = 5)	Longspine thornyhead	158 805	91	99	1	6
	Shortspine thornyhead	15 820	9	99	1	61
	Subtotal	174 625	100			
POP						
(n_j = 5)	Pacific ocean perch	16 883	99	73	27	1
	Aurora	121	<1	75	25	56
	Yellowmouth	61	<1	90	10	82
	Splitnose	9	<1	92	8	113
	Subtotal	17 074	100			
YWT						
(n_j = 30)	Yellowtail	580 767	>99	75	25	1
	Widow	1 208	<1	86	14	64
	Redstripe	503	<1	70	30	74
	Sharpchin	390	<1	70	30	99
	Subtotal	582 868	100			

Table 4 (*concluded*).

Market category[a]	Rockfish species	Landing estimate ($\hat{Y}_{.j}$)	Percent of market-category total landings	$\hat{V}_{BTW}$ %	$\hat{V}_{WTH}$ %	CV (%)
WDW						
(n_j = 38)	Widow	516 605	>99	85	15	1
	Yellowtail	2 459	<1	88	12	60
	Subtotal	519 064	100			
	Total	1 546 140				

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

Table 5. Species-composition estimates for the Newport/first quarter 1992 stratum. Landing estimates are in kilograms of fish.

Rockfish species	Landing estimate ($\hat{Y}_{..}$)	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	

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, Department of Mathematics and Statistics, The University of Calgary, Calgary, AB T2N 1N4, 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 avoided 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

Table 6. Age-composition summaries for groundfish landings in Oregon, January–December 1991. Landing estimates are in number of fish.

Groundfish species	Age	Landing estimate ($\hat{Y}_{\cdot j}$)	Percent of total landings	CV (%)
Yellowtail rockfish (n_j = 35)[a]	5	3 166	<1	82
	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 (n_j = 138)	4	614	<1	74
	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 (n_j = 17)	5	5 417	1	60
	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
	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 (n_j = 14)	2	37 561	1	63
	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	

Table 6 (*concluded*).

Groundfish species	Age	Landing estimate ($\hat{Y}_{.j}$)	Percent of total landings	CV (%)
Dover sole (n_j = 90)	4	1 932	<1	103
	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	≤115–104	
	Total	19 851 884	100	

[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.

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 exists 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 5) 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

Table 7. 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.

Age	Landing estimate ($\hat{Y}_{.j}$)	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			

Note: 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.

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 data bases that can be more readily accessed and interpreted than currently available.

Acknowledgements

I thank Mark Saelens, Neal Coenen, Jack Robinson, and Claire Wood of Oregon Department of Fish and Wildlife (ODFW) for their assistance during the development stages of this research. I am especially grateful to Mark and Claire, who provided valuable technical support, without which this study would not have been possible. I also thank the ODFW port biologists, Gary Hettman, Mike Hosie, Mark Freeman, Dave Douglas, and Tom Preston for their patience and helpful comments during my visits to the sampling sites. David B. Sampson and Amode R. Sen reviewed earlier versions of the manuscript and made useful criticisms. Two anonymous referees provided comments that helped improve the manuscript. This research was supported by the ODFW, Marine Resources Division, Newport, Oregon; and grant no. NA89AA-D-SG108 (project no. R-ES-16) from the National Oceanic and Atmospheric Administration to the Oregon State University Sea Grant College Program and by appropriations made by the Oregon State Legislature. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its subagencies.

References

Bazigos, G.P. 1974. The design of fisheries statistical surveys—inland waters. FAO Fish. Tech. Pap. 133.

Beddington, J.R., and eleven co-authors. 1984. Management under uncertainty (group report). *In* Exploitation of marine communities. Dahlem Konferenzen. *Edited by* R.M. May. Springer-Verlag, New York. pp. 227–244.

Cochran, W.G. 1977. Sampling techniques. 3rd ed. John Wiley & Sons, New York.

Doubleday, W.G. 1983. Sampling commercial catches of marine fish and invertebrates: summary and conclusion. Can. Spec. Publ. Fish. Aquat. Sci. 66. pp. 19–22.

Efron, B. 1982. The jackknife, the bootstrap, and other resampling plans. Society for Industrial and Applied Mathematics, Philadelphia, Pa.

Gulland, J.A. 1955. Estimation of growth and mortality in commercial fish populations. U.K. Minist. Agric. Fish. Food Fish. Invest. Ser. 2, **18**(2).

Gulland, J.A. 1965. Estimation of mortality rates. Mimeograph Report. Annex to Arctic Fisheries Working Group Report. ICES CM 1965 Gadoid Fish. Comm. 3.

Gulland, J.A. 1966. Manual of sampling and statistical methods for fisheries biology. Part 1. Sampling methods. FAO Man. Fish. Sci. 3.

Kimura, D.K., and Balsiger, J.W. 1985. Bootstrap methods for evaluating sablefish pot index surveys. N. Am. J. Fish. Manage. **5**: 47–56.

Larkin, P.A. 1972. A confidential memorandum on fisheries science. *In* World fisheries policy. *Edited by* B.J. Rothschild. University of Washington Press, Seattle. pp. 189–197.

McCallister, M.K., and Peterman, R.M. 1992. Experimental design in the management of fisheries: a review. North Am. J. Fish. Manage. **12**: 1–18.

Methot, R.D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50. pp. 259–277.

Parker, K.R., and MacCall, A.D. 1990. An interactive port sampling model for California groundfish. U.S. Natl. Mar. Fish. Ser. Admin. Rep. T-90-83.

Pelletier, D., and Gros, P. 1991. Assessing the impact of sampling error on model-based management advice: comparison of equilibrium yield per recruit variance estimators. Can. J. Fish. Aquat. Sci. **48**: 2129–2139.

Pope, J.G. 1983. An investigation of accuracy of virtual population analysis using cohort analysis. *In* Key papers on fish populations. *Edited by* D.H. Cushing. IRL, Oxford, England. pp. 291–301.

Pope, J.G. 1988. Collecting fisheries assessment data. *In* Fish population dynamics. 2nd ed. *Edited by* J.A. Gulland. Wiley, Chichester, England. pp. 63–82.

Pope, J.G., and Gray, D. 1983. An investigation of the relationship between the precision of assessment data and the precision of total allowable catches. Can. Spec. Publ. Fish. Aquat. Sci. 66. pp. 151–157.

Powles, H. 1983. Implications of accuracy of sampling on management advice. Can. Spec. Publ. Fish. Aquat. Sci. 66. pp. 6–9.

Quinn, T.J., II, Best, E.A., Bijsterveld, L., and McGregor, I.R. 1983. Sampling Pacific halibut landings for age composition: history, evaluation, and estimation. Int. Pacific Halibut Comm. Sci. Rep. 68.

Robins, C.R., Bailey, R.M., Bond, C.E., Brooker, J.R., Lachner, E.A., Lea, R.N., and Scott, W.B. 1991. List of common and scientific names of fishes. Am. Fish. Soc. Spec. Publ. 20.

Scheaffer, R.L., Mendenhall, W., and Ott, L. 1990. Elementary survey sampling. 4th ed. PWS-Kent, Boston, Mass.

Sen, A.R. 1984. Sampling commercial rockfish landings in California. NOAA Tech. Memo. NMFS-SWFC-45.

Sen, A.R. 1986. Methodological problems in sampling commercial rockfish landings. Fish. Bull. U.S. **84**: 409–421.

Shepherd, J.G. 1988. Fish stock assessments and their data requirements. *In* Fish population dynamics. 2nd ed. *Edited by* J.A. Gulland. Wiley, Chichester, England. pp. 35–62.

Som, R.K. 1973. A manual of sampling techniques. Heinemann Educational Books Ltd., London.

Stanley, R.D. 1992. Bootstrap calculation of catch-per-unit-effort variance from trawl logbooks: do fisheries generate enough observations for stock assessments? North Am. J. Fish. Manage. **12**: 19–27.

Sukhatme, P.V., and Sukhatme, B.V. 1970. Sampling theory of surveys with applications. 2nd ed. Iowa State University Press, Ames.

Tomlinson, P.K. 1971. Some sampling problems in fishery work. Biometrics, **27**: 631–641.

Appendix

This appendix presents formulae used to calculate landing statistics. All 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, p. 412–413). 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. Additionally, 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). Finally, I discuss the applicability of selected estimators to Oregon fishery sample data where appropriate.

Notation

Population parameters are denoted by capital letters. Sample estimators are denoted by small letters or by capital letters with a circumflex, depending on the statistic of interest. Total landing estimates and their associated variances are calculated as the sums of the individual stratum estimates.

Within a port/quarter stratum, to estimate (*i*) the weight of a given species in the landings (species-composition sampling program) or (*ii*) the number of fish of a given age, for a species of interest, in the landings (age-composition sampling program), the following set of parameters and statistics are used.

Boat trips (primary units)

N_j = total number of boat trips for market category j

n_j = number of boat trips sampled for market category j

Notes: (1) j = 1, 2, . . ., L different market categories (post-stratification 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 TYH market category.

Weight of fish

W_{ij} = total weight of all fish species in market category j of boat trip i

$W_{.j}$ = 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} = weight of basket k sampled from market category j of boat trip i

Baskets of fish (secondary units)

M_{ij} = total number of baskets in market category j of boat trip i

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

m_{ij} = number of baskets sampled from market category j of boat trip i

Landing variables

Y_{ij} = 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)

$Y_{.j}$ = 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)

$Y_{..}$ = 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 section.

y_{ijk} = 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 and discussion 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

$$\text{[A1]} \quad \bar{y}_{ij\cdot} = \frac{\sum_{k=1}^{m_{ij}} y_{ijk}}{m_{ij}}$$

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

$$\text{[A2]} \quad \bar{y}_{\cdot j\cdot} = \frac{\sum_{i=1}^{n_j} M_{ij}\bar{y}_{ij\cdot}}{\sum_{i=1}^{n_j} M_{ij}} \cong \frac{\sum_{i=1}^{n_j} W_{ij}\bar{y}_{ij\cdot}}{\sum_{i=1}^{n_j} W_{ij}}$$

Equation (A2) is a weighted estimator, where samples from boat trips with market-category landings that are large in size are given more weight in estimating $\bar{y}_{\cdot j\cdot}$ 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 $\bar{y}_{\cdot j\cdot}$; 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., $\hat{M}_{ij} = W_{ij}/\bar{w}_{ij\cdot}$, where $\bar{w}_{ij\cdot}$ is given by Eq. A5. Both empirical approaches in Eq. A2 utilize a ratio estimator, which is biased; however, the bias is negligible when n_j is large. Note that if the landing size of the market categories has no effect on the species compositions themselves, then weighting each sample mean, $\bar{y}_{ij\cdot}$, will have little influence on the final estimates generated in Eq. A2. One advantage of using a nonweighted estimator is that the estimated variance procedures are simplified. Additionally, if a nonweighted estimator is appropriate for a two-stage sampling design and the number of secondary units of fixed size is equal across the primary 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

$$\text{[A3]} \quad \hat{Y}_{.j} = \bar{y}_{.j.}\hat{M}_{.j}$$

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

$$\text{[A4]} \quad \bar{w}_{.j.} = \frac{\sum_{i=1}^{n_j} \bar{w}_{ij.}}{n_j}$$

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

$$\text{[A5]} \quad \bar{w}_{ij.} = \frac{\sum_{k=1}^{m_{ij}} w_{ijk}}{m_{ij}}$$

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 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

$$\text{[A6]} \quad \hat{Y}_{..} = \sum_{j=1}^{L} \hat{Y}_{.j}$$

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

$$\text{[A7]} \quad \hat{V}(\bar{y}_{.j.}) \cong \left(\frac{N_j - n_j}{N_j}\right)\left(\frac{1}{n_j \hat{\bar{M}}_{.j}^2}\right) s_{1j}^2 + \left(\frac{1}{n_j N_j \hat{\bar{M}}_{.j}^2}\right) \sum_{i=1}^{n_j} \hat{M}_{ij}^2 \left(\frac{\hat{M}_{ij} - m_{ij}}{\hat{M}_{ij}}\right) \frac{s_{2ij}^2}{m_{ij}}$$

where

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

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

and

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

Note that $\hat{\bar{M}}_{.j}$, 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 (i) 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 (ii) 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

$$\text{[A8]} \quad \hat{\bar{M}}_{.j} = \left(\frac{W_{.j}}{\bar{w}_{.j.}}\right)\left(\frac{1}{N_j}\right) = \frac{\hat{M}_{.j}}{N_j}$$

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

$$\text{[A9]} \quad \hat{V}(\hat{Y}_{.j}) \cong (\hat{M}_{.j})^2 \hat{V}(\bar{y}_{.j.})$$

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 Eq. A9 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

$$\text{[A10]} \quad \hat{V}(\hat{Y}_{..}) \cong \sum_{j=1}^{L} \hat{V}(\hat{Y}_{.j}) + 2\sum_{a}\sum_{<b} \mathrm{Cov}(\hat{Y}_{.a}, \hat{Y}_{.b})$$

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 Eq. A10. 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 that 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 Eq. A10. Given the above findings, Eq. A10 simplifies to

$$[\text{A11}] \quad \hat{V}(\hat{Y}_{..}) \cong \sum_{j=1}^{L} \hat{V}(\hat{Y}_{.j})$$

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

$$[\text{A12}] \quad \hat{V}_{\mathrm{BTW}} = \left(\frac{N_j - n_j}{N_j}\right)\left(\frac{1}{n_j \hat{\bar{M}}_{.j}^2}\right) s_{1j}^2$$

and

$$\hat{V}_{\mathrm{WTH}} = \left(\frac{1}{n_j N_j \hat{\bar{M}}_{.j}^2}\right) \sum_{i=1}^{n_j} \hat{M}_{ij}^2 \left(\frac{\hat{M}_{ij} - m_{ij}}{\hat{M}_{ij}}\right) \frac{s_{2ij}^2}{m_{ij}}$$

where s_{1j}^2 and s_{2ij}^2 are given by Eq. A7. 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 $\hat{V}_{\mathrm{BTW}}$ % and $\hat{V}_{\mathrm{WTH}}$ %, for the between and within components, respectively.