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A discussion paper on reconciling assessment and management of inshore rockfish

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Abstract

An integrated assessment and management strategy for inshore rockfishes (*Sebastes*) has eluded biologists and managers along the west coast of North America. Rockfishes are characterized by longevity, low natural mortality, and restricted mobility of adults relative to the capabilities of fishing fleets. A directed hook and line fishery for inshore rockfishes has become significant in British Columbia since the early 1980s, capitalizing particularly on the lucrative market for live fish.

The primary purpose of this paper is to propose a means of reconciling the difficulties of rockfish assessment with the demands of fishery management. Traditional fisheries models are rendered inadequate by discrepancies among the scales of biological processes for rockfishes, the activities feasible for assessment, and the pattern of exploitation. Key to this dilemma is a misunderstanding of the planning horizon required to manage populations that may cycle a single generation during the working career of fisheries biologists. Pragmatic simulation modeling is suggested as a basis for resolving the problems of (1) reconciling the time lag between application of a management tactic and realization of its effects, (2) communication among biologists, managers, and stakeholders, and (3) learning about the consequences of experimental manipulation given model assumptions.

In order to provide context for the proposed simulation modeling, the problems associated with assessment and management of inshore rockfishes are reviewed. A brief account of the history and current status of the directed hook and line fishery for rockfishes in British Columbia is presented, along with a description of available data. Removals of inshore rockfishes by other fisheries and as incidental catch are outlined. Assessment methods applied to inshore rockfishes along the west coast are reviewed. Recommendations are provided that revolve around a combination of large and small scale experiments, based on the results of simulation modeling. In order to refine the assumptions in simulation, increased research priority on rockfish life history is recommended. The evaluation of stock indices that explicitly incorporate life history (*e.g.* reproductive value) should be conducted in simulation and field research. Stakeholder involvement in planning experimentation and ongoing review of objectives is considered key to successful implementation of the simulation results.

Résumé

Les biologistes et les gestionnaires de la côte ouest de l'Amérique du Nord n'ont jamais réussi à instaurer une stratégie intégrée d'évaluation et de gestion pour les sébastes (*Sebastes*) côtiers. Les sébastes se caractérisent par une grande longévité, une faible mortalité naturelle et une mobilité restreinte des individus adultes comparativement à celle des flottilles de pêche. La pêche dirigée à la ligne et à l'hameçon des sébastes côtiers est devenue importante en Colombie-Britannique depuis le début des années 1980. Cette pêche vise surtout le marché lucratif du poisson vivant.

Le document a pour objectif premier de proposer un moyen de concilier la difficulté d'évaluer les stocks de sébastes et les besoins de la gestion des pêches. Les modèles des pêches traditionnels ne sont pas adéquats à cause des écarts entre les échelles des processus biologiques des sébastes, les activités se prêtant à l'évaluation et les régimes d'exploitation. Le problème peut se résumer à une mauvaise connaissance de la période de planification à appliquer à des populations dont le cycle d'une seule génération peut correspondre à la durée de toute la carrière d'un biologiste des pêches. On propose une modélisation par simulation pragmatique comme outil de base pour résoudre les problèmes 1) du décalage entre l'application d'une stratégie de gestion et la perception de ses effets, 2) de la communication entre les biologistes, les gestionnaires et les intervenants et 3) la connaissance des conséquences de la manipulation expérimentale dans le contexte d'hypothèses de modèle.

Les problèmes de l'évaluation et de la gestion des stocks de sébastes côtiers sont examinés dans le contexte de la modélisation par simulation qui est proposée. On trouve une brève description des antécédents et de l'état actuel de la pêche dirigée à la ligne et à l'hameçon des sébastes de la Colombie-Britannique, de même qu'une présentation des données actuelles. Il y est aussi traité de la récolte de sébastes côtiers par d'autres pêches et sous forme de captures accidentelles et l'on fait l'examen des méthodes d'évaluation appliquées aux sébastes de la côte ouest. Des recommandations sont formulées relativement à la combinaison d'expériences à grande ou à petite échelle reposant sur les résultats d'une modélisation par simulation. Il est recommandé d'accorder plus d'importance aux travaux de recherche sur le cycle vital des sébastes dans le but d'affiner les hypothèses de la simulation. Les indices des stocks qui incorporent explicitement le cycle vital (valeur reproductive, etc.) devraient être évalués par le moyen de la simulation et de recherches sur le terrain. La participation des intervenants à la planification des expériences et à l'examen continu des objectifs est jugée être un élément clé de la réussite de l'application des résultats de la simulation.

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1. Introduction

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An integrated assessment and management strategy for inshore rockfish species (*Sebastes*) has eluded assessment biologists and fishery managers along the west coast of North America. To the fisheries biologist, the inshore rockfish species complex presents the problem of understanding a variety of life histories, all of which have longevity and low natural mortality as key features. Each of the species are aggregated in distribution, with some members adopting a sedentary lifestyle oriented about specific habitat features (Archibald *et al.* 1983, Matthews 1990, O'Connell and Carlile 1991, Richards_1986a). These aspects of life history imply that rockfish populations display low productivity relative to short-lived species, such as hake, herring, or tuna (Francis 1986, Stocker and Leaman 1989), and that estimates of abundance are difficult to obtain with precision. In the case of inshore rockfishes, the fisheries manager is faced with the problem of making decisions with few data regarding a fishing fleet whose fishing capacity, like those of other fleets, may well exceed the long-term productivity of stocks.

The designation of "inshore" or "nearshore" rockfishes is one of convenience rather than a biological distinction. In British Columbia (B.C.), the inshore rockfish fishery is dominated by yelloweye (*S. ruberrimus*), quillback (*S. maliger*) and copper rockfish (*S. caurinus*), although redbanded (*S. babcocki*), rougheye (*S. aleutianus*), and silvergray (*S. brevispinis*) rockfish have recently been caught in quantity on the west coast of Vancouver Island and in the Queen Charlotte Islands. At least twenty species of rockfishes are landed in the fishery (Table 1.1). In B.C., inshore rockfishes are taken commercially with a category "Zn" license. A live, fresh round, and fillet market is supplied locally, as well as a fresh round and fillet market in the United States. The fishery is managed by Fisheries and Oceans Canada (DFO) in consultation with industry advisors.

The hook and line rockfish fishery utilizes a variety of gears ranging from longlines to hand lines (rod and reel, or downrigger). Longline gear fished by each vessel is not standardized, and may include a variable numbers of strings, hook spacing, hook types, and bait types. A vessel that fishes hand line gear may employ one or more rods or downriggers with single or multiple hooks. The various gear configurations may be used concurrently in the same area, but hand line gear tends to target rockfishes destined for the live market. Thus, interpretation of commercially derived catch and effort is highly gear dependent.

Species	Common name	Abbreviation	Code
Scorpaenidae	Scorpionfishes	SCORP	388
S. aleutianus	Rougheye rockfish	ROUGH	394
S. alutus	Pacific ocean perch	POP	396
S. auriculatus	Brown rockfish	BOLIN	398
S. aurora	Aurora rockfish	AUROR	400
S. babcocki	Redbanded rockfish	REDBA	401
S. borealis	Shortraker rockfish	SHORT	403
S. brevispinus	Silvergray rockfish	SILVE	405
S. caurinus	Copper rockfish	COPPE	407
S. ciliatus	Dusky rockfish	DUSKY	409
S. crameri	Darkblotched rockfish	DARKB	410
S. diploproa	Splitnose rockfish	SPLIT	412
S. elongatus	Greenstriped rockfish	GREEN	414
S. emphaeus	Puget Sound rockfish	PUGET	415
S. entomelas	Widow rockfish	WIDOW	417
S. flavidus	Yellowtail rockfish	YTAIL	418
S. goodei	Chilipepper rockfish	CHILI	420
S. helvomaculatus	Rosethorn rockfish	ROSET	421
S. jordani	Shortbelly rockfish	SBELL	423
S. maliger	Quillback rockfish	QUILL	424
S. melanops	Black rockfish	BLACK	426
S. miniatus	Vermillion rockfish	VERMI	428
S. mystinus	Blue rockfish	BLUE	429
S. nebulosus	China rockfish	CHINA	431
S. nigrocinctus	Tiger rockfish	TIGER	433
S. paucispinus	Bocaccio	LONGJ	435
S. pinniger	Canary rockfish	CANAR	437
S. proriger	Redstripe rockfish	REDST	439
S. reedi	Yellowmouth rockfish	YMOUT	440
S. ruberrimus	Yelloweye rockfish	YEYE	442
S. saxicola	Stripetail rockfish	STRIP	444
S. variegatus	Harlequin rockfish	HARLE	446
S. zacentrus	Sharpchin rockfish	SHARP	450

 Table 1.1 List of Sebastes caught by hook and line gear in British Columbia

The Groundfish Subcommittee of the Pacific Stock Assessment Review Committee (PSARC) recognized the assessment and management difficulties posed by inshore rockfishes when it recommended "... a rigorous review of alternative management approaches which are feasible from assessment and management perspectives, and which meet the Department's conservation mandate." (PSARC 1996). In particular, the Subcommittee noted the mismatch of spatial scale between the biology of rockfishes and activities which are practical for stock assessment and fisheries management (Rice et al. 1995, PSARC 1996). However, it can be argued that the difference in temporal scale between management actions and assessment capability is at least as important as the discrepancy in spatial scale. In their discussion of this issue, the Subcommittee suggested that marine protected areas (MPAs) may be an effective management tool, but advised that "...MPAs are unlikely to be effective, by themselves, as tools for sustainable management of inshore rockfish." Nevertheless, the Subcommittee considered refuges to be a form of spatial management necessary to the assessment and management of inshore rockfishes.

One objective of this paper is to respond to the PSARC recommendation. However, because the problems of management and assessment are inextricably linked for this fishery, it is important to provide context for the discussion by describing:

- 1. Problems associated with the assessment and management of inshore rockfishes that render traditional fisheries models inadequate;
- 2. The history and current status of the hook and line rockfish fishery in B.C.;
- 3. The range of the management tactics applied to the hook and line rockfish fishery that may affect data available for assessment;
- 4. Data available for assessment purposes, and the limitations of the data;
- 5. Methods used for the assessment of inshore rockfish species coast wide;
- 6. Removals of inshore rockfishes by other directed fisheries (*e.g.* recreational sector) and as bycatch.

Interpretation of the stock impacts of the directed commercial fishery is complicated by removals from other fisheries; these removals cannot be controlled _ through management tactics applied in the hook and line fishery. For example, recreational catch in the Strait of Georgia management region was estimated to be about the same as the Zn catch (Yamanaka and Richards 1992). A daily bag limit of five rockfish is applied to this fishery, a tactic that does not necessarily limit total catch. Thus, conservation concerns, and the harvest opportunities for inshore rockfishes can only be evaluated in light of all fishery removals. Landings are not limited to the Zn hook and line, trawl, and recreational sectors. Other removals of rockfishes can be attributed to salmon (*Oncorhynchus* sp.) troll, dogfish (*Squalus acanthias*), lingcod

(Ophiodon elongatus), and halibut (Hippoglossus stenolepis) bycatch and First Nations groundfish allocations.

In British Columbia, assessment and management of inshore rockfishes suffers from the following weaknesses:

- 1. Although many management tactics were intended to limit catch through effort restrictions, the current suite of tactics largely act to moderate the delivery of product to market rather than to achieve specific biologically-based strategies for conservation or long term production. Total allowable catch restrictions do provide an effective tactic, but the basis for the quota levels is not strongly supported by biological objectives that ensure sustainability;
- 2. Total removals of inshore rockfishes are not controllable by tactics applied only to the Zn fishery, and are not fully measured. For example, the recreational catch is monitored for some areas for a portion of the fishing year, while First Nations utilization is unknown.
- 3. There are relatively few field-based studies designed to explore production-driven processes (*e.g.* larval dispersal, recruitment, genetic basis for stocks). Basic biological parameters (*e.g.* age composition, fecundity, age-at-maturity) are well known for only a few rockfish stocks in British Columbia, notably Pacific ocean perch and yellowtail rockfish.

The PSARC Groundfish Subcommittee called for an investigation of alternatives to existing approaches for inshore rockfishes. This paper takes the perspective that that the search for alternatives and a means of ranking their potential utility will not proceed successfully without a framework for evaluation. There are some promising assessment methods under study on the west coast, as described in Section 6. However, the absence of a suitable means of judging alternatives in a management context precludes a selection among competing methods. Long-term progress relies partly on the accumulation of fishery dependent and independent data series. However, this paper suggests that the amount and nature of the required data can only be identified through concurrent modeling (see Section 8.1, Starfield 1997).

2. **Defining the Problem**

2.1 **Fuzzy objectives**

The PSARC request for this paper was motivated by the difficulties of providing assessment advice for inshore rockfish species. In part, this stems from confusion over the objectives for management of rockfishes. The 1997 management plan for the groundfish hook and line fishery stated that the objective was "... to ensure resource

conservation while providing for a viable and economically efficient groundfish fishery" (Fisheries and Oceans Canada 1997a). Framing the objective in this manner falls short of providing meaningful criteria or targets upon which to develop a management strategy, or to chose among various tactics for implementing the strategy.

This paper adopts the practice of Hilborn and Walters (1992) by making the distinction between the management strategy and management tactic explicit. They defined the strategy as a plan for determining how the catch removed from a stock is adjusted over time. The adjustments are based on the expected size of the stock, the economic and social value of the fishery, and uncertainty in biological data. Tactics are measures such as annual quotas, season limits, or gear restrictions that regulate how the management strategy is achieved. For example, a strategy might be to maintain a minimum spawning biomass or to remove a fixed proportion of the available biomass, subject to the long term sustainability of the population. The assessment problem is one of defining explicit measures or indicators for evaluating whether a particular management strategy has been achieved. The current inability to quantify resource conservation for inshore rockfishes, and to identify stock performance indicators, renders evaluation of the stated objective of the hook and line management plan operationally impossible.

The problem of fuzzy objectives for the management of the hook and line fishery is not unique among rockfish fisheries. Leaman (1991) concluded that confusion over the objectives of rockfish (*Sebastes*) management can be attributed to inappropriate application of management criteria for shorter-lived species. Maximum sustainable yield or equilibrium yield strategies have not been met for any rockfish species on the Pacific Coast (Pacific Fishery Management Council 1991) or world wide (Leaman 1987). Leaman (1991) proposed that some traditional fisheries approaches are weak because:

- 1. Stock and recruitment analysis holds little promise due to the weak relationship between the two variables (Archibald *et al.* 1983) and due to low stock production. The latter issue is one of low contrast in stock size over time. Lightly exploited stocks are likely to be stable in size due to low production, as are heavily exploited stocks maintained at low levels by fishing;
- 2. Fishery dependent catch per unit effort indices do not track abundance in a timely, precise, or unbiased manner;
- 3. Yield per recruit analysis inappropriately suggests high fishing effort because the decrease in biomass due to natural mortality becomes progressively greater than that to due an increase in growth. These methods also assume that natural mortality and growth are constant over the conditions examined, and may assume that the pattern of cohort strengths is insensitive to the harvest rate.

One of the reasons that traditional fisheries models fail is because they do not adequately deal with assessment data from spatially complex development patterns. The phenomenon of localized, or progressive, depletion of rockfish stocks has been noted on a

coarse scale for inshore rockfishes in the Gulf of Alaska (O'Connell and Bracken 1990) and in British Columbia (Yamanaka and Kronlund 1997a). The spatial pattern of depletion for Pacific ocean perch (*S. alutus*) was documented by Francis (1986). These observations of spatial depletion were based on catch per unit effort (CPUE) data aggregated over relatively large areas. Recent assessments of Pacific ocean perch in the Goose Island Gulley area of B.C. (Richards and Olsen 1996) and the Gulf of Alaska region (Heifetz *et al.* 1995) indicated some recovery from excessive harvest during the foreign fishery of the late 1960s and early 1970s. The recovery period has been on the order of 20 to 25 years, as predicted by Archibald *et al.* (1983).

For rockfishes, commercial CPUE has not been a timely index of population status (Richards 1994), usually indicating severe population decline well after the onset of excessive harvest. Catch per unit effort can track large changes in biomass (Leaman 1991), but may ultimately fail because rockfishes are attracted to specific bathymetry and fishing power tends to improve with technology. The mechanism for spatial depletion likely consists of a progressive decline of localized stocks with apparently low adult mobility. When data are aggregated over large management regions, hyperstability of CPUE can result because (1) fishers can move within the region to maintain catch rates, and (2) temporal trends in fishing power increase fishing efficiency. These effects may mask an actual decline in abundance within the management region. In the long term, resolving the appropriate spatial scale for the assessment of inshore rockfishes is critical (Mangel 1994) for several reasons:

- 1. Failure to identify the appropriate spatial scale makes it impossible to compare across species or systems (different species have different areas of production, and occupy various habitat and food web niches);
- 2. The scale of observation may not correspond to the appropriate ecological scale for solving a particular problem (*e.g.* what constitutes a stock for any species of inshore rockfish, or what is the appropriate size and spacing of harvest refuges?);
- 3. Observation on a single scale may be inadequate since different processes may operate on different scales.

For example, understanding the scale of biological production processes becomes critical to the design and implementation of marine refuges as a management tool (see Section 7.2).

2.2 Biological and fishery constraints

Rockfishes (Sebastes) exhibit specific life history features that encourage unsustainable harvest, render traditional fisheries models near useless, and offer little hope for the recovery of depleted stocks without radical management intervention (Archibald *et al.* 1983, Hightower and Grossman 1987, Walters and Collie 1989). For inshore rockfish stocks in British Columbia, there is currently no basis upon which to judge the sustainability of removals (PSARC 1996); the assessment data required to use traditional fisheries models (e.g. catch at age models) simply do not exist. There are limited biological data available over areas and species, and across time (Yamanaka and Kronlund 1997a). The relevant spatial scale is unclear, and alternative approaches such as marine protected areas are unproved. The empirical basis for judging sustainability can only be established by the accumulation and analysis of time-series information about rockfish populations exposed to various harvest regimes. Much of the necessary data will require on the order of two decades or more to amass. Although necessary, passive collection of commercial catch and effort through landing validation or logbooks are unable to provide much near term guidance to fishery managers on harvest level. Even direct manipulation following the adaptive management strategies proposed by Walters and Collie (1989), or those implemented by Leaman and Stanley (1993), are unlikely to significantly shorten the time required to gather assessment data in support of management. These strategies may shorten the time required to learn about harvest driven processes, but will do little hasten learning about production-based processes. However, experimental manipulation should be incorporated into any management and assessment plan for inshore rockfishes, as described in Section 7.3.

There are two fundamental features of *Sebastes* life history that confound their assessment and management. The first is related to their longevity and, therefore, low rate of natural mortality. Maximum lifespan in *Sebastes* is estimated at 20-140 years (Leaman 1991). For example, techniques described by MacLellan (1997) have determined the maximum ages for rockfishes in British Columbia at 98 years for yelloweye rockfish, 76 years for quillback rockfish, and 45 years for copper rockfish. Estimates of instantaneous natural mortality, M, for adult rockfishes are in the range of 0.02 to 0.08 for lightly exploited stocks based on the analysis of catch curves (Archibald *et al.* 1981) or on empirical studies of natural mortality (Hoenig 1983). These life history parameters contribute to populations that are typified by a large standing stock prior to exploitation with apparently low rates of production. Thus, a fishery can flourish initially based almost entirely on the accumulated biomass as opposed to new recruitment (Francis 1986).

The second feature of life history that constrains management of rockfishes relates to their propensity for contagion whether the species are pelagic, semi-pelagic or benthic. In the case of some benthic species, such as quillback, copper, and brown rockfishes, there may be a high degree of fidelity to home ranges or specific habitat features (Matthews 1990, Matthews and Reavis 1990). Within the bounds of any given habitat, further degrees of aggregation exist due to behavioral reasons or feeding requirements. There are two consequences for assessment that result from this behavior:

- 1. Exploitable concentrations of rockfishes can be predictably targeted by fishers enabling stable catch per unit effort in spite of declining absolute biomass;
- 2. Estimates of biomass using classic survey techniques have a large variance component attributable to spatial distribution. Considerable temporal variance

components due to localized seasonal migration, fortnightly behavior, or diel changes in vertical distribution occur, in addition to the spatial variability.

In addition to longevity and habitat affinity, rockfish life histories do not permit significant compensation for shifts in adult mortality. Leaman (1991) found relatively small changes in growth and maturity due to density dependent effects in *S. alutus*. For example, age at first maturity was only 1 to 4 years younger in heavily exploited (instantaneous fishing mortality, F=0.6) stocks compared to that in lightly exploited (F=0.02) stocks, a difference only slightly larger than normal inter-cohort variation in size at age (size and maturity are highly correlated). Resultant increases in fecundity at age were estimated to be only 10 to 15 percent, which were small compared to the loss of life-time reproductive output associated with a drop in mean age from 25-35 years to 14-16 years. This evidence suggests there is little optimism for large compensatory responses in growth and fecundity in response to significant increases in fishing mortality for *S. alutus*.

Rockfish populations are likely characterized by periods of relatively low, but variable, recruitment punctuated by large spikes in recruitment that occur infrequently, perhaps once a decade for *S. alutus* (Leaman 1991). Other members of the genus may well depart to some degree from this pattern. Given the variable recruitment pattern for *S. alutus*, and the relatively long reproductive life (30 to 60 years) for rockfishes in general, it is important to consider the distribution of fecundity within and among cohorts in stock assessment. At present there is little information to suggest different reproductive contributions among cohorts to a strong year class. For example, does a strong year class result when the older component of the population makes a strong reproductive biology, and possible environmental interactions, to determine the relevant triggers for strong year classes.

Additional constraints on assessment and management are created by the nature of the fishery. As many as 22 species of rockfishes are landed by hook and line gear (Table 1.1). A general principle of multi-species fisheries is that the more diverse the fishery in terms of gears, species, and areas, the more biologically conservative the management strategy must be if the objective is to ensure sustainability of each species (Francis 1986). In the case of inshore rockfishes, the constituent species in the fishery and the gear types contribute to a diverse fishery, where CPUE indices from longline and hand line gears are not directly comparable. When other sources of removals are considered, such as the recreational fishery and bycatch mortality, the assessment biologist must essentially evaluate several different fisheries on the same complex of species. This requirement exists even when only one fishery might be used to index stocks and for judging the potential effectiveness of control measures. For example, it may do little good to diminish removals in commercial sectors when the recreational sector is not similarly limited.

The difficulties created by uncertainties over the appropriate spatial scale for assessment and management compound the problem. Management of the inshore

rockfish fishery in B.C. is currently resolved to the level of the management region (Figure 2.1), although total allowable catches have been provided at the level of the statistical area. This is not a defense of the spatial resolution of the assessments, however, since there has been little work conducted to identify the scale of inshore rockfish population dynamics (*e.g.* recruitment, reef fidelity, migration, larval dispersal, minimum spawning concentration, stock identification). There is a need for finer spatial resolution, but traditional management tactics to control effort (seasonal and area closures) would require an impossible level of detail about the spatial distribution of stocks, and fishing areas would be too small to manage effectively (Walters and Pearse 1996).

2.3 Windows for assessment and management

The failure of traditional fisheries management and assessment techniques for rockfishes can, in part, be attributed to the time lag between the management intervention and the interpretation of fishing effects. Leaman (1991) argued that the window of opportunity for detection, action, and response to the effects of management tactics is 10 to 20 years for many *Sebastes*. Leaman focused on *S. alutus*, which has a maximum observed age of 90 years and a generation time of 20 to 30 years; a window of similar duration can be expected for yelloweye and quillback rockfishes (maximum ages 98 and 76 years, respectively). The window should be correspondingly shorter for copper rockfish, which have been aged to 45 years. These considerations suggest that within-year observations of population measures are less relevant to long-term strategies than accumulated observations on the scale of decades.

Corroboration for this assessment of feedback time can be found in the results of a simulation study conducted by Francis (1986). He performed a series of age-structured simulation studies modeled after Walters (1969) and used current best estimates of growth, natural mortality, and age-dependent catchability. In addition, two recruitment functions were investigated, one that assumed constant recruitment over all stock levels and a second that assumed density-dependent recruitment. He simulated equilibrium yield as a function of fishing mortality. The primary results of the simulations for Pacific ocean perch and yellowtail (*S. flavidus*, maximum age 45 year for females, 60 years for males) rockfishes can be summarized as follows:



Figure 2.1 Management regions for inshore rockfishes in British Columbia.

- 1. When equilibrium yield is simulated as a function of fishing mortality, surplus production is 1 to 5 percent of the unexploited biomass;
- 2. Unfished rockfish stocks were capable of maintaining 10 to 20 times the maximum sustained yield (MSY) during the first five years of the simulation at effort levels not much in excess of effort at MSY. This resulted because of large initial biomass and because the effects of fishing on recruitment are not felt in the initial period due to late recruitment to the fishery (age 15 at 100% recruitment);
- 3. Simulations measured the time required to recover from the biomass, *B*, corresponding to 50% of that which would support maximum sustained yield (MSY) to a biomass that was 95% the amount at MSY for three effort levels: (1) no fishing effort, (2) 50% of MSY effort, and (3) MSY effort. Times to recovery ranged from a decade for yellowtail rockfish at no fishing effort to over 80 years for Pacific ocean perch at MSY effort. The simulations were performed using the assumption of density dependent recruitment;
- 4. Once a rockfish stock is fished down to levels that impact recruitment, the stock will take on the order of decades to recover to a level capable of sustaining as little as 5-10% of the yield that it produced in the fishing up period.

Francis' (1986) commentary on the management implications of fisheries on rockfishes were that "... the biological nature of these species seems to preclude their recovery from overfishing while still maintaining any semblance of a viable and productive fishery." This conclusion is buttressed by the results of Walters and Collie (1989) and Hightower and Grossman (1987) that indicate complete cessation of fishing is the optimal rebuilding tactic for severely depleted stocks. However, see assessments of Pacific ocean perch stocks by Richards and Olsen (1996) and Heifitz *et al.* (1995) that suggest some recovery of stocks coincident with a fishery.

However, these results are largely determined by the sequence of cohort strengths. An extremely large year class (e.g. 1952 and 1976 for S. alutus) would have produced results not seen in the simulations performed by Francis (1986). The advent of a strong year class, in absolute rather than relative terms, has important consequences for fishery managers, particularly if it arises from a depleted stock or from one stock among many. The former argues that rockfish can be fished to very low levels of spawning biomass with impunity, while the latter suggests localized stock and recruitment relationships. In any event, managers need to be advised that while "boomer" year classes are possible, they remain unpredictable and infrequent.

The results of Francis (1986) for Pacific ocean perch and yellowtail (S. flavidus) rockfish are directly applicable to inshore rockfish species on the basis of longevity and age composition. At first glance, it might appear that density-dependence of some form must be assumed in a precautionary strategy. However, a competing model might be considered for rockfishes where annual recruitment fails to provide stock maintenance in

most cases, but sporadic strong year classes serve to ensure sustainable populations at any population level (this model points to reproductive value as an index, see Section 6.5). Like that of most marine species, the stock and recruitment relationship is not well known for *Sebastes*, but alternative formulations are not likely to change the time horizon of the simulation results. Nevertheless, given current interest in harvest refuges, a revised suite of similar simulations incorporating spatial components may be warranted. The ability to experiment with a simulation model with known assumptions under a variety of management scenarios is a key step towards raising appreciation for the need to increase the planning horizon for inshore rockfishes from annual activities to a time frame on the order of decades.

2.4 **Resolving the problem**

The Groundfish Subcommittee of PSARC requested a rigorous review of alternative management approaches for the inshore rockfish fishery. Past efforts to make progress on management issues for hook and line rockfish have focused on how available biomass is allocated among the fishers (*e.g.* monthly and trip limits, stacking of trip limits, area licensing, individual quotas, individual transferable quotas). Although the allocation issue is critically important to the economy of the fishery, and to increased flexibility for DFO in terms of fleet rationalization, it does little to address the fundamental impasse created by unclear strategies and the absence of reliable performance measures for assessment.

Progress on assessment of inshore rockfishes in British Columbia has been hampered the lack of operationally useful objectives for management, resource limitations, and the absence of cost-effective method suitable for estimating biomass. This situation is common to inshore rockfish fisheries along the west coast of North America, and to most shallow-water reef fisheries in temperate and tropical climates. For example, the Report of the Nearshore Rockfish Management Workshop (Pacific States Marine Fisheries Commission March 1-2, 1994) concentrated on (1) determining the population status of inshore rockfishes, (2) managing and selecting harvest rates for inshore rockfishes, and (3) reconciling harvest management and public perception of harvest management with rockfish population status. The workshop included participants from government agencies in Alaska, British Columbia, Washington, Oregon and California. The conclusions of the meeting were that (1) in most cases managers do not have sufficient information to determine the abundance levels of inshore rockfishes, (2) the political process governing rockfish management operates on a short time frame, while the longevity of the genus implies a slow response to rehabilitation measures (in contrast, the time required to over harvest stocks may be short, on the order of a few years), and (3) there are insufficient technical tools and resources to determine with precision the biological data necessary to manage the species.

Barring the development of radical improvements in remote sensing technology (e.g. acoustic techniques), it is unlikely that methods will develop that enable rapid assessment of population status. In the absence of a technological solution that delivers

reliable stock indicators on a broad spatial scale, how can management alternatives be evaluated and decisions made with few data? This paper identifies three components to reconciling management strategies with assessment for the inshore rockfish fishery:

- 1. The adoption of pragmatic modeling (sensu Starfield 1997) using the best current biological knowledge about Sebastes population dynamics and hook and line fleet dynamics. Starfield (1997) described a pragmatic approach to modeling natural resources in data poor situations. In essence, he argued that it is better to proceed with simulation modeling on the basis of what is known, rather than avoiding modeling because there are too few data or unreliable data. In Starfield's view, the value of modeling experiments with explicit assumptions is based as much on what is learned by building the model, as on the accuracy of the model or its ability to forecast. Computer simulations of management and assessment in a fisheries context have suggested that a simplified (not simplistic!) model may be a better tool than detailed models that use more data and require more parameters be estimated (Walters and Pearse 1996).
- 2. Identification and implementation of experimental harvest strategies on a variety of spatial scales that include a range of harvest levels (refuges to deliberate overfishing). Harvest management for purposes of information gathering has been considered in the past for *Sebastes* (Walters and Collie 1989) and actually implemented in two cases (Leaman and Stanley 1993). Experimentation in a spatially structured manner can allow empirical demonstration of the effects of various harvest rates without exposing the entire resource to risk. Closed areas can serve to buffer against over-exploitation and to ensure conservation (Hilborn and Walters 1992). This protection assumes that stock maintenance in protected areas is internal to their boundaries (see Carr and Reed 1993).
- 3. Cooperative involvement of stakeholders (Zn fishery, recreational sector, general public). Removals of inshore rockfish species can be attributed not only to the directed Zn fishery, but also to the recreational sector, First Nations, and bycatch in the directed halibut, dogfish, and salmon troll fisheries. With the growing interest of the general public in marine protected areas, the number of potential stakeholders is growing rapidly for inshore rockfishes and other species such as lingcod.

3. Status of the Hook and Line Fishery

3.1 Data sources

Catch and effort data documenting removals of inshore rockfishes are drawn from a variety of sources including:

- 1. The historical (1956 to 1995) commercial fish slip database;
- 2. The hook and line dockside monitoring program (implemented in 1995);
- 3. Zn fishery logbooks (implemented in 1986);
- 4. Recreational catch creel surveys (seasonal coverage by area);
- 5. The groundfish trawl database.

These disparate data sources are not linked in any convenient manner, and the spatial and temporal resolution possible with the historic data is variable. The data sources are numerous since inshore rockfishes are landed in the directed Zn hook and line fishery and occur as target species in the trawl and recreational fisheries, and as bycatch in the halibut, dogfish, lingcod, and salmon fisheries. A significant amount of groundfishes are allocated to First Nations, but actual removals of rockfishes by First Nations are unknown.

Descriptions of data sources along with tabular and graphical summaries were presented by Yamanaka and Kronlund (1997a) and updated by Yamanaka and Kronlund (1997b). The logbook database is described by Haigh and Richards (1997). Catch and effort statistics for the trawl fishery are summarized most recently by Rutherford (1996). A summary of recreational creel survey data was presented by Yamanaka and Richards (1995). The Strait of Georgia creel survey was last described by Collicutt and Shardlow (1992). Angler interviews and aerial overflights provide recreational catch per unit of effort and total fishing effort for some statistical areas (Section 4.2). These data are combined to estimate the total catch of salmon and groundfish in the recreational fishery and total recreational fishing effort.

The limitations of the various data relevant to stock assessment are described in the following list:

- 1. Catch by species: Commercial fish slips resolved catch by weight into the species categories "red snapper" (predominately yelloweye rockfish) and "other rockfish" (variable species composition, depending on area). Logbooks for the Zn fishery offer improved accounting of catch (pieces) by species since 1993, however logbook data collected from 1986 to 1992 contain variable reporting of catch by weight, pieces, or both. Dockside monitoring provides validated catch (weight) by species beginning in 1995. Rockfishes have been identified to species in some years of the Strait of Georgia creel survey, but catch estimates are provided for rockfishes without regard to species. Catch is measured as pieces and converted by weight using a constant 0.7 kg.
- 2. **Resolution of fishing location**: The spatial resolution of fish slip data was to DFO statistical areas, although the data do not distinguish between statistical areas inside and outside the surf line. Logbook data allow fishing locations to be

geo-referenced by latitude and longitude (degrees, minutes). Compliance with geo-referencing has improved greatly in recent years, but is variable prior to 1993. Dockside monitoring data is resolved only to the level of a management region. In theory, if logbook data and dockside monitoring data were linked, the spatial resolution of the validated landings could be better determined.

- 3. Determination of effort: Effort was resolved to a fishing day using commercial fish slip data. The dockside monitoring program does not allow estimation of effort. Logbooks potentially offer improved estimates of soak time and the number of hooks deployed for longline gear, and finer resolution of time fished each day for hand line gear and hooks fished. It is not clear, however, that fishing time, or time in conjunction with the number of hooks set, actually measures effort since search time may not be reflected in the recorded data. For recreational creel surveys, effort is recorded variably as the number of boat trips observed in each month or as the number of angler days.
- 4. Determination of gear: Gear type was captured by the fish slip database, but is not available in electronic format prior to 1982. Logbook and dockside monitoring data include gear type.
- 5. **Resolution of trips and sets**: The logbook data contain catch and effort data resolved by set and trip, with the exception of data prior to 1994 which does not contain a trip identifier.
- 6. **Biological sampling**: Biological sampling of inshore rockfishes is extremely limited. There is no effective systematic program for the collection of biological samples from the commercial catch, although various attempts have been made through port sampling and cooperative programs with industry. Various research catch and effort surveys have collected biological data (Richards and Cass 1987; Richards and Hand 1987; Richards *et al.* 1988; Yamanaka and Richards 1993). Opportunities to collect biological data through a cooperative program with industry have not materialized. This program involved obtaining samples from prescribed location in each management region using a standardized 500 hook string of gear set at a specified location and depth.

3.2 Fishery trends

Annual catch and effort time series derived from commercial fish slip data are shown in Figure 3.1 for the "red snapper" species category and in Figure 3.2 for the "other rockfish" species category. The time series are separated by management region (rows) and gear type (columns) in each figure. Effort is not comparable between longline and hand line gears.

The fishery for "red snapper" (primarily yelloweye rockfish) is dominated by the longline fisheries in the west coast Vancouver Island and Queen Charlotte Island

management regions. Catches increased after 1989 in anticipation of limited entry, which was implemented in 1992 for the Strait of Georgia, and in 1993 for the "outside" fishery (all regions except the Strait of Georgia). Declines in total catch since limited entry have occurred in large part due to reduced total allowable catches of yelloweye rockfish.

The "other rockfish" species category (all species excluding yelloweye) is dominated in the Strait of Georgia by hand line gear, and by longline gear in other management regions. Total catch by longline gear from the west coast Vancouver Island and Queen Charlotte Islands regions increased markedly in 1994 and 1995, primarily due to large catches of rougheye and red-banded rockfishes. Regional summaries of catch and effort data are provided by Yamanaka and Kronlund (1997b).

Total hook and line catch (tonnes) of rockfishes by species in 1996 is shown in Figure 3.3 for the five management regions. Data for this analysis were derived from the dockside monitoring program. The labeling of species for each panel corresponds to the abbreviations listed in Table 1.1. The dominant species in the catch varies by region, but primarily consists of quillback, yelloweye, copper, rougheye, red-banded, and silvergray rockfishes. Although over 20 species of *Sebastes* are landed, relatively few species explain the majority of the catch. For example, two or three species account for the majority of the catch in the Strait of Georgia, Central Coast, and North Coast regions.



Figure 3.1 Catch (tonnes, solid line) and effort (days fished, dashed line) of "red snapper" by gear type as determined from commercial fish slip data. Time series from 1982 to 1995 are shown for five management regions (SG=Strait of Georgia, WC=West Coast Vancouver Island, CC=Central Coast, NC=North Coast, QC=Queen Charlotte Islands).



Figure 3.2 Catch (tonnes, solid line) and effort (days fished, dashed line) of "other rockfish" by gear type as determined from commercial fish slip data. Time series from 1982 to 1995 are shown for five management regions (SG=Strait of Georgia, WC=West Coast Vancouver Island, CC=Central Coast, NC=North Coast, QC=Queen Charlotte Islands).



Hook and Line Rockfish Catch in 1996 (tonnes)

Figure 3.3 Catch weight by species in 1996 for the five inshore rockfish management regions (NC=North Coast, QC=Queen Charlotte Islands, UNK=Unknown, SG=Strait of Georgia, WC=West Coast Vancouver Island, CC=Central Coast).

4. Other Sources of Removals

This section provides an indication of the historical removals of rockfishes from sources other than the Zn fishery. A number of sources of bycatch exist including the halibut, salmon, dogfish, and lingcod hook and line fisheries. Trawl accounts for a small component of removals of traditional "inshore species". The recreational sector takes significant quantities of rockfishes, while the removals of First Nations allocations are unknown. Minor bycatch of inshore rockfishes occurs in the shrimp beam trawl fishery, mid-water hake and pollock fisheries, and the Option B flatfish trawl fishery in the Strait of Georgia. Updated catch information for some of these removals is provided in Yamanaka and Kronlund (1997b).

4.1 Bycatch of rockfishes

Bycatch of rockfishes in the halibut fishery has been permitted as a percentage of the halibut quota. The rockfish allowance ranged from 15 to 20 percent by weight from 1991 to 1996, and was reduced to 10 percent in 1997. The bycatch was 4.4 percent by weight of halibut landed in 1991, 5.8 percent in 1992, 10.4 percent in 1993, 4.9 percent in 1994, and 7.7 percent in 1995 (source: Archipelago Marine Resources). Mixed Zn rockfish and halibut landings were permitted in 1993 and 1995. Rockfish bycatch for 1995 and 1996 is listed by species in Table 4.1. The percentage bycatch was 7.7 percent in 1996. The current management plan for halibut stipulates that vessels are permitted to retain rockfishes to a maximum of 10 percent of the total net weight of halibut onboard. Within the 10 percent total, a maximum one percent by weight of fresh round quillback, copper, tiger, and china rockfishes may be retained..

Trawl catch of rockfishes varies among the management regions, with significant quantities of rougheye, red-banded, and silvergray rockfishes landed in the west coast Vancouver Island, Queen Charlotte Island, and Central Coast regions (Yamanaka and Kronlund 1997b). These species are allocated largely to the trawl sector. Coast wide trawl landings of quillback, copper, china rockfishes in 1996 were 12, 14, and 1 tonnes, respectively. Landings of yelloweye rockfish were greater, at about 31 tonnes coast wide. A significant amount of canary rockfish were landed (506 tonnes) by trawl coast wide.

Bycatch of rockfishes in salmon troll, sablefish, and dogfish fisheries was last assessed in 1992 (Yamanaka and Richards 1992, their Tables 11.10 and 11.11). Directed dogfish fishing accounted for a large proportion of incidental catch of rockfishes, in particular for the Strait of Georgia region. Rockfish bycatch resulting from directed fishing on lingcod was last assessed by Richards and Yamanaka (1992, their Table 2.3). In the period from 1983 to 1992, the proportion of lingcod landings that also landed rockfishes ranged from 86 to 98 percent.

Species	1995 Total (lbs)	1995 Percent	1996 Total (lbs)	1996 Percent
YEYE	543,448	74.0	533,242	72.3
REDBA	62,146	8.5	63,303	8.6
ROUGH	33,213	4.5	35,766	4.8
QUILL	33,883	4.6	40,335	5.5
IDIOTS	15,672	2.1	17,851	2.4
YMOUT	5,653	0.8	9,071	1.2
SHORT	13,277	1.8	10,776	1.5
SILVE	11,261	1.5	10,883	1.5
CANAR	4,777	0.7	6,976	0.9
LONGJ	3,227	0.4	3,232	0.4
VERMI	408	0.1	1,289	0.2
COPPE	796	0.1	1,351	0.2
CHINA	621	0.1	1,183	0.2
TIGER	1,094	0.1	1,190	0.2
OTHERS	7,777	1.1	1,574	0.2
Total	734,856	100.0	738,022	100.0

Table 4.1 Bycatch of rockfishes in the halibut fishery for 1995 and 1996.

4.2 Recreational catch

The recreational creel survey in the Strait of Georgia is comprised of angler interviews to provide estimates of catch per unit effort, and aerial observation to provide estimates of total effort in the study area (Collicutt and Shardlow 1992). The survey is stratified by month, geographic area, day type (weekday, weekend), time of day, and type (guided, non-guided). The catch of rockfishes has been reported to species in some years of the creel survey for some areas, but this practice is variable (*e.g.* Collicutt and Shardlow 1992). Recently, the coverage of the survey has been reduced to peak fishing periods from early spring to late fall. Total rockfish catch by statistical area is shown in (Table 4.2). Note that annual trends are not directly comparable because of changes in the temporal coverage of the survey.

Table 4.2 shows that the sum of catches across all statistical areas in the Strait of Georgia is likely to be about the same as the directed Zn fishery catch, when prorated over a year. Thus, control measures applied to the Zn fishery may not be effective in reducing total rockfish removals if the sport catch is not similarly controlled. Currently, the management tactic applied to the recreational fishery in the Strait of Georgia is a daily bag limit of five rockfishes; a daily bag limit of eight rockfishes is in effect outside the Strait of Georgia. Since sport effort is uncontrolled, the bag limit is likely to be an inefficient tactic.

Table 4.2 Estimated total catch (tonnes) by statistical area for the Strait of Georgia recreational catch survey. Areas 19A is Saanich Inlet and area 19B includes the remaining portions of area 19 and the portion of area 20 east of Sheringham Point. All catch was converted from pieces to tonnes using an average weight per piece of 0.7 kg. Catch marked with *b* cover July and August only, while *c* indicates June through August.

Year	Months	12	13	14	15	16	17	18	19a	19b	28	29	All
1983	Jan-Dec	-	26.0	12.5	2.7	29.4	16.4	16.5	7.1	19.0	10.4	6.4	146
1984	Jan-Dec	-	15.9	10.1	3.0	11.3	24.7	14.2	3.6	14.4	7.6	5.6	110
1985	Jan-Dec	-	10.1	8.7	1.2	27.0	14.5	8.5	3.9	10.3	5.0	4.6	94
1986	Jan-Dec	-	14.8	14.5	1.9	34.2	12.9	9.0	4.2	15.9	4.9	5.0	117
1987	Jan-Dec	-	11.5	15.9	2.1	14.4	16.1	10.4	4.1	15.5	2.9	2.5	.95
1988	Jan-Dec	-	17.3	21.0	2.0	26.7	21.4	12.0	4.4	20.0	4.2	7.4	136
1989	Jan-Dec	-	13.1	22.3	2.2	33.9	23.6	13.9	3.5	16.9	4.2	6.3	140
1990	Jan-Dec	-	13.0	16.7	1.7	30.2	11.1	5.6	5.8	14.3	4.4	5.5	108
1991	Jan-Dec	9.2 ^⁵	12.0	16.4	1.5	33.8	14.4	5.9	3.1	9.3	8.3	16.6	121
1992	Jan-Dec	10.3°	10.4	9.7	0.9	30.5	12.6	6.7	2.9	11.5	5.1	4.7	95
1993	Jan-Sep	9.3°	11.1	6.5	0.9	14.6	10.5	3.7	1.1	13.6	3.9	7.1	73
1994	Jan-Oct	-	20.0	17.6	2.0	21.6	14.3	4.6	3.0	4.0	9.1	9.1	105
1995	Mar-Oct	-	13.5	8.7	1.6	20.0	10.5	3.9	3.0	6.8	3.7	5.8	78
1996	Apr-Sep	-	16.4	3.0	1.3	19.8	5.6	2.9	3.8	7.4	1.7	5.4	67

A creel survey is conducted in Barclay Sound (statistical areas 23 and 24) where the catch of rockfishes has ranged from an estimated 7.5 to 18 tonnes per annum (Yamanaka and Kronlund 1997b). Recreational catch estimated in statistical areas 1 through 10 by a creel survey program (undocumented) increased to 12 tonnes in 1996 from 2 to 3 tonnes in the early 1990s.

4.3 **First Nations catch**

Communal licenses for First Nations include allocations for halibut, sablefish, and "other groundfish" categories. The other groundfish category includes inshore rockfish species, but does not identify aggregate or species specific allocations. Approximately 136 tonnes (300,000 lb) of other groundfish are allocated to communal licenses coast wide. Actual removals are undocumented. However, it is believed that nearly all rockfish consumption by First Nations is comprised of inshore and shelf species, accounting for perhaps 75 to 80 percent of groundfish landed excluding halibut and sablefish (F. Crabbe, pers. comm.). An estimate of approximately 100 tonnes of rockfishes equates to a per person consumption of about 2.5 kg per year.

4.4 Discarding

There is no mandatory on-board observer program for the hook and line fishery, thus, the level of discarding cannot be quantified. Regardless of whether discarding is a problem, conditions in the hook and line fishery encourage the practice:

- 1. The payment a fisher receives for a live rockfish (primarily quillback and copper rockfishes) is four to five times that of a filleted fish;
- 2. When the market is fully supplied, a live rockfish in the 1.5 lb to 2 lb weight range is worth more than live fish outside the preferred range;
- 3. Anecdotal reports from fishers and the Hook and Line Advisory Committee are that fish buyers will not buy or pay low prices for spawning females, reportedly because of aesthetics in market live tanks;
- 4. Fishing period limits for Aggregate 1, or Aggregate 2 limits, may be reached prior to the yelloweye limit, leading to discarding of A1 and A2, and vice versa.

5. Management Tactics

Fisheries and Oceans Canada produces annual management plans (see for example Fisheries and Oceans 1997) that state management tactics for the hook and line fishery. There is no formal strategy for this fishery in the sense of a quantitative statement of how much catch is taken under various circumstances. The overall limiting tactic is a total allowable catch (TAC) applied to selected groups of species. However, the TACs are not based on, for example, a constant exploitation rate policy such as an $F_{0.1}$ strategy or a size-limit strategy. In the former case, stock size cannot be reliably estimated, while a size-limit would not be age selective for rockfishes. The suite of management tactics applied to inshore rockfishes has evolved over the last decade to include a wide range of concurrent measures (Appendices 1 and 2). This increase in the number of tactics applied to the fishery each year, particularly since 1992, complicates the interpretation of catch and effort data derived from logbooks. For example, the accumulation of tactics for the Strait of Georgia management region is shown in Table 5.1. The pattern of management restrictions has roughly followed the common phases in fishery regulation described by Hilborn and Walters (1992, p. 116). Because management tactics can influence fishery-dependent indices (Richards 1994), it is the purpose of this section to describe the various tactics applied to the hook and line rockfish fishery.

Gear has always been restricted to hook and line (*e.g.* longline, hand line, troll). Size-limits and sex-specific harvest restrictions have not been used to manage rockfishes. The hook and line rockfish fishery was unrestricted prior to 1986 when seasonal closures were initiated. A variety of seasonal closures and bycatch closures were implemented from 1987 to 1991 (Appendices 1 and 2). Seasonal closures were attempted to reduce effort, and thus limit catch, although the management plans do not state this intent. Explicit quotas were set for the first time in 1991 for the yelloweye (50 t) and other rockfish (300 t) species categories in the Strait of Georgia. Total allowable catch restrictions based on stock assessments were first applied in 1991 for the Strait of Georgia region. License limitation was implemented in 1992, which reduced the number of

licenses from 592 to 74 in the Strait of Georgia "Inside" fishery. In 1993, limitation for the coast exclusive of the Strait of Georgia (the "Outside" fishery) resulted in a reduction in the number of licenses from 1,591 to 183. The development of a live fishery has been actively encouraged by management policy formalized in 1994 for the Strait of Georgia:

"All rockfish species (Sebastes sp.), with the exception of yelloweye rockfish, shall be landed alive. The number of live rockfish (exclusive of yelloweye rockfish), in pieces, shall not be less than eighty percent (80%) of the total number of rockfish pieces (exclusive of yelloweye rockfish) landed at any time. Yelloweye rockfish may be landed dead or alive". (1994 Management Plan: Groundfish by Hook and Line).

Although the data are not available, it is reasonable to expect that fishing power has increased over the last decade due to improvements in electronic depth sounders and navigational aids, and experience. Essentially, the component of effort related to search time may be reduced by technology and experience, with the result that recorded effort represents efficient fishing time. In recent years, Zn fishers may be better motivated due to poor salmon seasons and license limitation (both qualifying for and benefiting from limited entry).

The time required to implement harvest strategies and detect the corresponding response in the fishery may exceed the working career of a fishery manager. Thus, it is critical to maintain a detailed corporate record of the management history. Management plans do not contain this history since they reflect management intent prior to a fishing season, rather than what actually happened during the season. For example, variation orders were used prior to 1995 to change management tactics as quotas were approached. Since 1995, each fisher receives an amendment for a fishing period, which may change throughout a fishing year.

Year	Fixed	Catch-limited	Annual	Limited	Fishing	Options	Aggregates
	Season	Season	TAC	Entry	Periods		
<1986							
1986	•						
1987	۲						
1988	•						
1989	•						
1990	•						
1991	•	•	٠				
1992	•	•	•	•			
1993	•	•	۲	•			
1994	•	•	٠	•			
1995	۲	•	•	•	•	•	•
1996	۲	۲	•	•	•	•	•
1997	۲	•	•	•	٠	•	•

Table 5.1 Summary of management tactics applied to the Strait of Georgia fishery.

5.1 Fixed season closures

Prior to the implementation of quotas in 1991, the fishery was closed from approximately the beginning of the calendar year to early spring. The stated reasons for the closure were to (1) reduce levels of effort, (2) to coincide with the lingcod closure, and (3) to prevent fishing during the presumed spawning period for rockfishes, (4) weather, and (5) markets. However, the West Coast Vancouver Island (WC) and Strait of Georgia (SG) management regions currently open April 15 and June 15, respectively, and may remain open well into the winter. The remaining three management regions open January 1 until quota is achieved under various trip and fishing period limits. Thus, coincident closure with lingcod spawning closures and protection of rockfishes during spawning are not achieved and the seasonal closures function mainly to stagger the delivery of product to market.

5.2 Total allowable catches

The hook and line fishery for rockfishes was first subject to total allowable catch (TAC) limits in 1991, although assessments provided recommended yield options beginning in 1986 (Stocker *et al.* 1987) which were used to estimate the length of fishing season required to achieve the yield. The yield recommendations were based on trends in landings, CPUE, fishery participation and biological sampling from catch and effort surveys prior to 1992 (*e.g.* Richards 1986b, 1988, 1989, Richards and Hand 1990). Beginning in 1992, area-based assessment of productivity based on catch history was used to compute yield options (Yamanaka and Richards 1992). The TAC is the only management tactic that provides effective limitation of harvest, but the sustainability of yield recommendations cannot be evaluated (PSARC 1996).

5.3 Catch-limited openings

In many years, a portion of the total allowable catch (TAC) for certain species was _ allocated for an initial opening. When this allocation was achieved, the balance of the quota of was used as bycatch in directed fishing on other species. For example, in 1995 = directed fishing on yelloweye rockfish was prohibited after 90 percent of the yelloweye quota was achieved. Directed fishing on quillback, copper, china, and tiger rockfishes, however, was allowed to continue, with the balance of the yelloweye quota used as bycatch (Appendix 2). In 1996, the Central Coast management region was open January 1 until 60 tonnes of the quota was achieved. The Central Coast fishery re-opened after November 1 for the balance of the quota (Appendix 2). Similarly, the 1994 management plan specified that quillback, copper, china, and tiger rockfishes be opened June 15, 1994 in the Strait of Georgia until 140 tonnes was achieved, re-opening December 1, 1994 for the balance of the TAC (Appendix 1). These limitations were implemented (1) to avoid overruns on quota for species categories, (2) to take advantage of higher prices in the live

market during the December to January period, and (3) to distribute catch over the fishing year.

5.4 Area closures

Area closures have been used for a variety of reasons unrelated to rockfish catch limitation. For example, closures of subareas may occur to address conservation concerns for other species (*e.g.* herring spawn areas, salmon and herring holding areas), ensure First Nations harvest, avoid gear conflicts (*e.g.* crab gear, designated sport fishing areas), habitat protection (*e.g.* shallow water environments and the immediate vicinity of the Fraser River delta), and because of harbor and military exclusion zones. In most cases, sport fishing is not prohibited in areas closed to commercial fishing. There are no areas where complete cessation of fishing activity has been enforced for reasons of rockfish conservation. An experimental closure was introduced in Area 7 beginning in 1991, where subareas are closed for two years on a rotational basis. Although the attempt to rotate harvest was laudable, there was no corresponding limitation of harvest or effort within Area 7 to adjust for the closed subareas. The rotation period of two years is also too short given the longevity and age of maturity for *Sebastes*.

5.5 Species aggregates

Prior to 1995, annual quotas had been assigned to the "red snapper" (RS) and "other rockfish" (OR) species categories (Table 5.2). Beginning in 1995, the number of categories was increased to include yelloweye (YE) and 6 additional species aggregates (A1-A6). The number of aggregates was again increased in 1997 to a total of 7 groups (Table 5.2). For the Strait of Georgia management region, the "other rockfish" category (OR) is the same as aggregate 1 and 2 combined, so aggregate management did not cause a change in historical management in this region, *per se*. Note, incidentally, that historical management plans designate "other rockfish" to be comprised of quillback, copper, china, and tiger rockfishes whereas stock assessments have considered other rockfishes to be all species except yelloweye.

Year	Aggregate	Species
<1995	YE	yelloweye
	OR	quillback, copper, china, tiger
1995	YE	yelloweye –
	A1	quillback, copper
	A2	china, tiger
	A3	canary, silvergray, yellowtail, widow
	A4	rougheye, shortraker, shortspine and longspine thornyheads
	A5	Pacific ocean perch, yellowmouth, redstripe
	A6	all other species (Sebastes) except YE and A1-A5
> 1995	YE	yelloweye
	A1	quillback, copper
	A2	china, tiger
	A3	canary, silvergray
	A4	rougheye, shortraker, shortspine and longspine thornyhead
	A5	Pacific ocean perch, yellowmouth, redstripe
	A6	yellowtail, black, widow
	A7	all other species (Sebastes) except YE and A1-A6

 Table 5.2 Rockfish aggregates in the Zn Hook and Line Fishery.

The intent of rockfish aggregates is to allow management where the basis of production is the aggregate, rather than a single species or stock (Rice and Richards 1995). Within each species aggregate, some stocks are expected to increase in abundance, other stocks may decline. Performance indicators should be related to the trajectory of the aggregate of stocks, rather than the individual performance of each constituent stock. Rice and Richards argued that the management requirements for an aggregate are substantially less than those required for single species, stock-based production units.

For the inshore rockfish fishery, it is not clear that aggregate management can work, for the very reason pointed out by Rice and Richards (1995): harvesting should_not jeopardize individual aggregate constituents in decline, nor target those on the increase. This requirement arises because the drawbacks for species under harvest pressure are greater than the benefits to species that are not targeted in the aggregate; stocks can be fished down more rapidly that the expected rate of rebuilding in the absence of harvest. For the hook and line fishery, the species of preference are quillback and copper rockfishes, both of which command a comparatively high price in the live market relative to yelloweye (YE) and Aggregate 2 (A2). For Aggregate 1 (A1), it is not clear that the desired objective of variable performance of constituent species over time can be achieved with only two species in the aggregate, where each species is highly desirable economically. Since there are no significant spatial refuges for YE and species in A1 or A2 which cannot be fished by hook and line gear, the likelihood of stocks of each species providing buoyancy for the aggregate trajectory is low, particularly in the face of spatial depletion.

Despite the conceptual attractiveness of aggregate management, the basic problem of measuring the performance unit remains even when there is no management requirement for single-species assessment. The management strategy remains unspecified in the sense that there is no quantifiable biological basis for judging the success of the tactic (e.g. long term sustainability). The live market upon which the Zn fishery heavily depends adds a dynamic not anticipated by the current scheme of aggregates. There are anecdotal signs of increasing value for rockfish species in the live market that have been considered uneconomical to harvest in the past. The development of new target species will change the assumption of representative harvest that led to the original selection of constituent species in each aggregate. In theory, aggregate management accommodates changes in the contribution of each component species to the landings from the aggregate. However, there is limited ability to distinguish natural fluctuations in species availability from serial depletion of species in the inshore rockfish complex. What is not recognized by the current management approach is the protracted length of time required to allow depleted species in an aggregate to return to levels approximating historical production.

5.6 Fishing options

Fishing options were implemented beginning in 1995 to accommodate participation in the fishery by all classes of hook and line vessels. Fishers could select from three fishing options (Appendix 2) where limitations were imposed on different species aggregates within each option. Fishing options work in concert with fishing period catch limits to regulate the pace of landings and to make the fishery accessible to a variety of vessels. This management tactic was introduced for several reasons, including concern about excessive targeting on yelloweye rockfish and to provide for diversification into other rockfish species judged not to be fully exploited by the trawl sector. In 1996, the outside fishery included a live fish option (option A), a yelloweye rockfish option (option B), and a rougheye and shortraker rockfish option (option C).

5.7 Fishing period catch limits

Catch limitation within a fishing period was introduced in 1995. This measure was proposed by industry and managers as a tactic for reducing effort and distributing the annual TAC over a longer season. The fishing periods are not the same for all license holders, rather the date of the licensee's first rockfish landing determines the commencement of his first fishing period each year. Subsequent fishing periods commence on the same date of each following month (see, for example, the 1995 Management Plan: Groundfish by Hook and Line). There are no restrictions on the number of landings each fishing period.

The limits within a fishing period change annually, which makes fisherydependent catch and effort data difficult to interpret. For example, catch restrictions for license holders in the Strait of Georgia have changed each year from 1995 to 1997 (Table 5.3). Similar changes have been applied to fishing period limits for the outside hook and line rockfish fishery. It is not clear that this tactic has been effective in reducing effort. In general, effort restrictions are less efficient than direct restrictions on catch.

Limit	1995	1996	1997
A1	3500 lb.	1800 lb.	1500 lb.
[•] A2-A6	< 20% of	na	na
	A1,YE/landing		
A2-A7	na	600 lb.	600 lb.
A3-A7	< landed weight		
	A1/period		
YE <	6000 lb.	2500 lb.	2500 lb.
Cap			
YE>	Added to A2-A6 after	<20% of A1/landing	<20% A1/landing after
Cap		after 26t	- 24t
Overage	maximum 20% A1	maximum of 10% of	maximum of 10% of
Ū.	deducted from next	A1-A7,YE deducted	A1-A7,YE deducted
	period	from next fishing period	from next period

Table 5.3 Fishing period limits for the Inside category Zn License (SG).

6. Assessment Methods

This section reviews the assessment methods currently used on the west coast of North America for inshore species, and for selected species classified as slope or shelf rockfish by DFO.

6.1 Catch per unit effort and catch history

Commercial catch per unit effort (CPUE) has been used as an indicator of stock abundance for rockfishes (Yamanaka and Kronlund 1997a, Palsson *et al.* 1996). At best, however, CPUE may act as a "late warning" system for decline in population abundance, revealing only that changes in population status occurred at some time in the past. Catch per unit effort is not a likely measure of stock status for a number of reasons (Hilborn and Walters 1992), but fails for rockfishes in particular for the following reasons:

- 1. The tendency for rockfishes to aggregate at specific habitat features (Archibald *et al.* 1983, Matthews 1990, O'Connell and Carlile 1993, Richards 1986a) means that CPUE can be maintained despite declines in biomass;
- 2. The hook and line fleet is able to search for more productive locales within large management regions when fishing becomes uneconomical at the current fishing locale (hyperstability of CPUE);

- 3. Technological improvements in on-board electronics (global positioning systems, the ability to electronically store and recall productive locales exactly, sonar equipment) means that the fishing power of vessels has increased over time. See Archibald *et al.* (1983) for an example of how changes in fishing power can change the scale of a CPUE based abundance index for *Sebastes*;
- 4. The dynamic nature of the management scheme affects the comparability of fishery-dependent indices among years.

Richards (1987) developed a model for using hook and line survey CPUE to index abundance of inshore rockfishes, however, further progress on fishery-independent CPUE measures for inshore rockfishes has been limited.

Catch history has been widely used in fisheries to recommend yields where there are few other data available. This approach is dependent on the accumulation of a long time series of catches under a relatively constant management regime. The use of catch history for inshore rockfish species in B.C. is difficult to support given the longevity of the species relative to the length of available time series. Historical fish slip data date to 1956, but do not resolve catch to species. The Zn logbook data are available since 1986, but are of variable quality from 1986 to 1992. An artificial spike in landings was introduced about 1990 in anticipation of limited entry restrictions. Thus, data that distinguish catch by species at improved spatial resolution coincide with a period of instability in the fishery introduced by changes in management.

6.2 Habitat-based analysis

Two forms of habitat-based analysis have been used on the west coast for inshore rockfish species. The two methods incorporate (1) scaling catch history by estimated habitat area, or (2) scaling *in situ* estimated density by habitat area. For British Columbia inshore rockfishes, a habitat based assessment was introduced in 1992 that recommended yield options for the species categories red snapper and other rockfish in each of 31 statistical areas on the coast (Yamanaka and Richards 1992). Refinements to the habitat areas were made in subsequent years (Yamanaka and Richards 1993b; 1994, 1995; Yamanaka and Kronlund 1997a). Specifically, the habitat-based assessment procedure included the following steps:

- 1. Estimate the habitat area for a species (e.g. yelloweye or quillback rockfishes) within each statistical area;
- 2. Divide the time series of annual catch by the habitat area to produce a catch density series for each statistical area;

- 3. Determine low and high risk catch densities from the catch density series, survey data, and biological data, where available;
- 4. Calculate low and high risk yield options by multiplying the low (high) risk catch density by the habitat area associated with a species.

Where a catch history is not available for a given area, a reference area may be used. Indeed, even where catch history for constituent areas within a management region is available, a single statistical area may be used to determine area-based production for low and high yield options (*e.g.* Yamanaka and Kronlund 1997a). Habitat was estimated by computing the bottom area bounded by the fished depth ranges for quillback and yelloweye rockfishes, as determined from logbooks. Bathymetric contours from digitized hydrographic charts were used to interpolate a bottom surface using a distance weighted - smoothing algorithm at a resolution of one hectare. All bottom areas recorded as "soft" on the hydrographic charts were excluded from the area calculations.

In Alaska, biomass of adult yelloweye rockfish is derived as the product of estimated density from submersible dives (for all rocky habitats), the estimate of area of suitable habitat within the 200 m contour, and average weight of fish from port samples by management area (O'Connell and Carlile 1993). The surveys consisted of line transects, with estimated densities corrected using a distance weighted detection function. The estimated density of adult yelloweye rockfish in the Central Southeast Outside management area (CSEO) is 2,929 fish/km². Recommended quotas were set at 2% of the lower bound of a 90% confidence interval on the biomass for a given region (O'Connell and Carlile 1995).

These methods share several common features:

- 1. The methods do not include a forecasting ability so that annual assessment data must be collected to provide advice each year;
- 2. Habitat area is assumed to be known (not a likely assumption);
- 3. Life history is not considered explicitly, although it could be argued that 2% of the lower bound of the 90% confidence interval for Alaskan biomass estimates acknowledges the low rate of natural mortality for yelloweye rockfish.

For the habitat method used in B.C., sustainability is not established for the reference areas since the available data span much less than several generations of the stocks. Also, it is not clear where the basis for production in a given reference area is located, *i.e.* the reference area may be sustained from adjacent areas rather than from internal sources.

There is likely to be considerable uncertainty about the overall habitat size. In addition, the known habitat affinity of inshore rockfishes (O'Connell and Carlile 1993, Richards 1986a, Matthews 1990), means that careful estimation of the habitat types comprising the sum of habitat area is required. Improved categorization and estimation

of habitat area is being pursued by the Alaska Department of Fish and Game (ADF&G) through the use of side-scan sonar (T. O'Connell, pers. comm.). To date, the estimated habitat area has been derived entirely from habitat descriptions contained on bathymetric charts. Habitat-specific density estimates were based on *in situ* classification of habitat type. The ADF&G initiated a project in 1994 to use sidescan sonar to help delineate available habitat and identify areas of key habitat types in the Edgecumbe offshore lava field, an important fishing ground in the Central South East Outside (CSEO) area. In 1996, an expanded sidescan program collected bathymetry data concurrently with the sidescan data. The result was a large mosaic of 700 sq km of seafloor off Kruzof Island, which covers approximately one fourth of the entire area of CSEO. The information enables a diverse habitat characterization (*e.g.* plutonic rock, sand and silt, cobble, a lava surface exhibiting well defined and little eroded aa and pahoehoe lava, lobate lava fronts, collapsed lava tubes, volcanic cones, and fault scarps). These habitat classifications were verified with direct observations from a submersible.

The diversity and distribution of rockfish species appeared to be related to habitat and depth; the occurrence of appropriately sized refuge spaces is a key to inshore rockfish occurrence. For example, yelloweye rockfish were significantly more abundant in areas with refuge spaces (i.e. caves, large cracks, overhangs or in boulder fields). In the study area, one of two adjacent large volcanic cones had significantly more fishes, both in terms of abundance and diversity. The sidescan sonar showed that the cone with greater fish densities has a field of immense boulders on the flank of the pinnacle that provides refuge habitat not available on the other pinnacle. When fish density data is collected for the specific habitat categories mapped by the sidescan sonar, estimates of abundance and biomass can be refined on a habitat-specific basis. Essentially, the sidescan data serves to reduce the uncertainty in estimating habitat area by type.

As noted above, the method used in British Columbia suffers since the catch history is used to select yield options, although direct observation of rockfish density has been documented in B.C. (Richards 1986a). The method may be effective only to the extent that past production in reference areas reflects productivity in areas to which they are applied (Leaman 1993). However, the method does provide for the distribution of fishing effort among statistical areas over the presumed habitat. Unfortunately, this advantage is lost in practice because inshore rockfishes are managed to the level of management regions, which are comprised of many statistical areas. While, the development of habitat-based assessment in B.C. is relatively new, it unfortunately coincides with a period of instability in the fishery when limited entry was introduced (Figure 3.1, Figure 3.2). The spike in landings preceding limited entry effectively cuts the time series in half, so it is unclear how best to estimate the long term area-based production units. Furthermore, it is hard to support the assessment of sustainable fishing based on the recent decade of catch data, when the expression of fishing effects in stock dynamics is not likely to be apparent for 20 to 30 years.

These criticisms are not intended to preclude work on area-based production. Rather, they are intended to stimulate further evaluation of the concept along the lines of work conducted for tropical reef fisheries (Polunin and Roberts 1996) which share similar patterns of exploitation, and similar species biology in terms of longevity and habitat affinity. Indeed, some habitat component is required to augment the accumulation of long term series on a coast-wide basis. For example, habitat information is required to assess the performance of marine protected areas and the effects of small scale manipulations.

6.3 Catch at age analysis

Catch and effort data has been collected for stocks of Pacific ocean perch (S. alutus) in British Columbia since the 1950s. Catch at age analyses have been conducted since the early 1980s (Archibald et al. 1983, Richards and Olsen 1996) for Pacific ocean perch, and surveys have been conducted for almost 20 years (e.g. Yamanaka et al. 1996, references therein) in support of their assessment. This species has experienced significant contrast in stock size due to fishing mortality, a feature that improves the ability of catch at age models to detect the trajectory and magnitude of a stock. Catchage analyses have also been applied to S. flavidus (Stanley 1995), using commercial catch per unit effort as the stock index. Age-structured data have been collected for other rockfish species, but are sparsely distributed in space and time; there are insufficient data for other species to support catch at age methods.

The prospects for accumulating data required for catch at age analysis even for the major species (*e.g.* quillback, copper, yelloweye) in the inshore rockfish fishery are not good. Approximately 15 to 20 years of data was required to enable the use of catch at age methods for *S. alutus*. A fishery-independent index of stock biomass is considered crucial to minimizing model bias and adequate indexing of stock size. Trawl surveys cannot be used to index rocky reef dwelling rockfishes, while hook and line biomass surveys have yielded mixed results (Richards 1987).

An additional factor that diminishes the prospects of using catch at age methods is the multi-species nature of the hook and line fishery. Francis (1986) cited the PFMC groundfish management team, which concluded that the total yield from a multi-species rockfish fishery would be about half of what the combined stocks are capable of producing to protect depleted species. In the specific situation of concern to the PFMC, protection of yellowtail rockfish meant that canary and other rockfishes would have to be grossly under-harvested. As a solution, the groundfish management team recommended that assessment become more detailed by increasing spatial resolution or by single species management. This is a daunting task for *Sebastes* landed in the hook and line fishery, given that the collective effort of Canadian rockfish biologists and industry over the last 20 to 30 years has accumulated a time series of commercial catch and effort data in concert with a fishery independent stock index for *S. alutus* only.

However, the experience gathered in the pursuit of catch at age analysis of S. *alutus* is relevant to the problem of inshore rockfishes for two reasons:

- 1. Stock assessment of a single species of *Sebastes* using catch at age methodology was first applied to 15 years of accumulated data from the period 1963 to 1977 after considerable investment of resources. Thus, it is unlikely to expect catch at age methods to be a short or middle term solution to inshore rockfish assessment;
- 2. In the absence of data for other *Sebastes*, life history parameters determined for Pacific ocean perch (*e.g.* Learnan 1987, 1991) can be used to guide simulation. At least in a broad sense, perch data can be used to determine a plausible population response to fishery effects for other members of the genus.

Almost certainly, species in the inshore rockfish species complex will have life history parameters that differ from those of *S. alutus*, and the population response to fishing effects of relatively shallow water, benthic members of the genus may prove to be different. However, available biological data for inshore species, in concert with what is know for *S. alutus*, are the best current data to guide field and simulation research.

6.4 Video acoustic transects

The Washington State Department of Fish and Wildlife (WDFW) is developing a method called the VAT, or "Video-Acoustic Technique", to estimate fish densities using an underwater video camera and a split-beam echosounder (Palsson and Pacunski 1995). To date, surveys using the VAT have been conducted in Puget Sound and the Strait of Juan de Fuca to estimate densities of quillback and copper rockfishes, and lingcod. In summary, a series of systematically spaced sites are occupied in the study area, and a platform mounted camera is deployed to a maximum depth of 37 m. The camera is used to record fish density within 2 m of the bottom, while the echosounder is used to obtain biomass estimates for fish more than 2 m off the bottom. Habitat is characterized by video observation and species identification is good within the limits of prevailing visibility (G. Workman, pers. comm.).

Biomass estimates are computed based on VAT observations and assuming simple random sampling; no habitat specific density estimates are computed. Little work has been done to date on survey design in terms of area and depth stratification. As is the case with other habitat-based methods, there is uncertainty in the estimated area for expansion of density to abundance. Difficulties were encountered obtaining species composition for the acoustic measurements. Analysis of logbook data from British Columbia indicated that quillback rockfish were caught from 0 to 90 m depth, while yelloweye rockfish were caught from 50 to 200 m depth. Thus, the VAT methodology is currently limited to sampling the fraction of rockfish populations residing shallower than 37 m. At present, there is no indication of how biomass derived from density estimates will be used as a stock indicator for assessing management targets. Even if it is not practical for estimating the density of rockfishes at all depths, the VAT technology may be very useful for small scale experimentation (*e.g.* assessing MPAs situated on shallow reefs).

6.5 Reproductive value

Reproductive value was proposed by Leaman (1987, 1991) as a practical index of stock status for *Sebastes*. This concept has not been applied to rockfishes to date. Leaman used a definition of reproductive value based on Fisher (1930): "... the average number of young that a female (genotype) of arbitrary age in a stable age distribution can expect to produce at that age, and over the remainder of her life, relative to a female at birth". Leaman, however, did not propose examining the genotype explicitly. Reproductive value is related to evolutionary fitness, and is closely linked to reproductive effort in that one measure of reproductive value is the summation of reproductive effort over reproductive life. Computation of reproductive value requires:

- 1. A representative sample of the age composition;
- 2. Fecundity at age measurements;
- 3. An estimate of mortality.

For example, one measures of reproductive value is total reproductive value (TRV):

$$TRV_a = \sum_{j=a}^m \left(N_j E_j \right) \quad ,$$

where, N_j is the number of fish aged j, and E_j is the fecundity at age j, for the maximum age m and age of reproductive value a.

Learnan (1987) simulated equilibrium populations of S. alutus using exponential mortality equations, a partial recruitment vector, and a stochastic Ricker stockrecruitment relationship (recruitment variation about 30%). He examined four different measures of reproductive value in simulations over 200 years using different levels of fishing mortality, F. The response of all reproductive value indices was continuous and linear with changes in fishing mortality, and two indices were relatively sensitive to changes in F. Learnan did not report simulations of commercial CPUE, but demonstrated that CPUE failed to track abundance after a biomass reduction of 50 percent for the Goose Island Gulley stock of Pacific ocean perch (Learnan 1991). The failure of commercial CPUE to track abundance was attributed to attraction of perch to the shelfslope break and increases in fishing power, both of which served to maintain CPUE. However, he did not compute the reproductive value indices for the Goose Island Gulley stock to determine if the indices could accurately track biomass.

The arguments in favor of reproductive value as a stock index are that it is relatively cheap to obtain, given that a representative age composition can be sampled, or that estimates of mortality among age groups are available (total instantaneous mortality, Z). Leaman concluded that reproductive value is more closely linked with population change than CPUE since it is based on a sample of age composition and fecundity. The uncertainty associated with the estimate of the age composition of the population is one

principal limitation of reproductive value. Also, the basic data comprising reproductive value must be measured continuously to determine inter-annual variability, *e.g.* is fecundity at age subject to systematic change induced by environmental conditions? Another important issue is that reproductive value, like any competing index, requires a reference point for operational use. This may mean introducing contrast in the index by experimentation to assess stock resilience as measured by reproductive value. Finally, Learnan did not detail practical application of reproductive value indices in the absence of an age structured simulation or a catch at age analysis.

7. **Competing Tactics**

The purpose of this section is to describe some tactics that have not been applied to inshore rockfish fisheries to any significant extent. These tactics should be investigated in the course of any future simulation modeling.

7.1 Fine scale control of effort and distribution

Traditional management tactics such as area closures (distinct from a harvest refuge) and seasonal closures to restrict the area accessible to the fleet are probably ineffective as control measures for inshore rockfish fisheries. The required resolution of species distributions would be too fine, and the size of fishing areas too small to be enforceable and economical (Walters and Pearse 1996). These tactics have been applied to the hook and line fishery with the intent of limiting effort and therefore catch, but likely serve only to distribute effort over a longer season and to moderate the supply of fish to market.

7.2 Marine zoning

The Canada Oceans Act provides for the establishment and management of Marine Protected Areas (MPAs) for the conservation and protection of marine resources and habitat (Fisheries and Oceans Canada 1997b). The Act provides for, but does not require, MPAs to be "no take" zones; regulation of fishing activity can be related to the level of harvest, closures, or gear use. For this reason, the term "marine zone" is used in this document to distinguish it from a marine protected area in which no harvest is permitted (Bohnsack 1996). The discussion paper on MPAs (Fisheries and Oceans Canada 1997b lists several goals of marine zones as a fisheries management tool:

- 1. A marine zone could provide recruitment surplus to the protected area that naturally migrate into unprotected areas, thereby replenishing fish stocks;
- 2. A marine zone may provide protection for fish depleted fish stocks;

- 3. A marine zone could provide refuge for specific life history stages (*e.g.* spawning aggregations or nursery areas);
- 4. A marine zone can provide insurance against unanticipated events (e.g. climate change).

There is little evidence from temperate waters, and no studies specific to rockfishes, to demonstrate that marine zones can provide distributed benefits in the form of recruitment to unprotected areas (Dugan and Davis 1993). Most refuges in existence today are small, having been established for conservation or research rather than as fisheries management tools, and few have been evaluated for their contribution to commercial or recreational fisheries. Given that rockfishes recruit at 8 to 10 years of age, it unlikely that this evidence will be available in the near future. In fact, the "source and sink" view of marine zones can just as well be reversed; a refuge may be dependent on larval production from unprotected areas. In general, there has been insufficient work on the performance of refuges; perceived benefits may have existed prior to the creation of a given protected area. For example, a particular site may be an attraction zone to some species, so that its value as a marine zone should be assessed by comparison with baseline data collected prior to establishment of the zone. Nevertheless, marine zones should be evaluated as a fisheries management tool in British Columbia simply because there are few data with which to judge their utility. In the end, the value of marine zones may be in their role as insurance in the face of uncertainties in assessment and management.

The results of a rare example of work on temperate zone harvest refuges are described in Appendix 3. Several "no take" refuges were established in Puget Sound specifically for the protection of *Sebastes* and lingcod. Copper rockfish within refuges were found to be more numerous and larger than those in harvested area. The results for quillback rockfish were mixed, with the highest density of quillback rockfish observed at one of the fished sites. However, this work should be followed closely over the short term, since the analysis of two more years of SCUBA survey data associated with video transect surveys is forthcoming (W. Palsson, pers. comm.).

A recent workshop (17-19 September 1997) was convened by the National Oceanographic and Atmospheric Administration (NOAA) Office for Protected Resources entitled "Marine Harvest Refugia for West Coast Rockfish". The workshop included plenary talks followed by meetings that focused on management, design, and social aspects of marine refuges. Proceedings of the workshop are forthcoming. Workshop participants delineated three categories of refuges (B. Leaman, pers. comm.):

- 1. Heritage refuges (less than 5 percent of the habitat). Intended to be representative of habitat (not unique habitat) and replicated. Their purpose would be to provide reference areas for researching fishing and environmental change, and are not intended for fisheries management.
- 2. Fisheries Buffer refuges (5 to 20 percent of the habitat). Intended to preserve essential fish habitat for specific species. These refuges should encompass the

complete home range of the target species and should be dispersed widely within the habitat. These refuges could function as an auxiliary fisheries management tactic.

3. Alternative Strategy refuges (20 to 50 percent of the habitat). Intended to be used in lieu of traditional fisheries management tactics for multi-species complexes. These refuges should incorporate a diversity of habitats including all life history stages and oceanographic features.

The intent of this scheme is not to allocate habitat to each of the refuge categories using the stated percentages. Rather, the categories represent competing choices to be used in conjunction with other management measures.

This categorization of refuges is not new; Carr and Reed (1993) identified similar classes of MPAs in their review of conceptual issues relevant to refuges. The central tenets of their framework were that (1) the importance of marine zones to fisheries management should be judged primarily on the ability of the refuge to supply recruits to harvested areas, and (2) that larval distribution provides the key mechanism to distributed production, rather than emigration of older individuals. However, in contrast to the "alternative strategy refuge" Carr and Reed concluded that marine zones could function to supplement, rather than replace, traditional management tactics.

The critical issues affecting the use of marine zones in British Columbia for rockfishes are related to design (how big, how many, where) and performance assessment. The current understanding of larval dispersal for *Sebastes* does not identify a clear design choice. Carr and Reed (1993) discussed four basic models of larval dispersal, and examples of *Sebastes* can be matched to three of the models:

- 1. Closed populations: Larval recruits are supplied to local population, but there is little exchange of larvae to other population. Harvest refuges are of little value to fisheries management in this situation since adult inhabitants contribute few recruits to harvested areas.
- 2. Single source: Larval recruits are supplied to populations throughout a region primarily from a single spawning stock, *e.g.* blue rockfish, *S. mystinus* (Love *et al.* 1991). Marine protected areas must be located within the spawning population at the major source of larval production.
- 3. Multiple source: Isolated breeding populations supply larvae to a common pool from which recruits are drawn into each isolated population, *e.g.* bocaccio, *S. paucispinis*. A network of refuges distributed throughout a region is desirable to protect against the risk of losing all refuges to natural or human intervention.
- 4. Limited distance: Essentially, populations that are nearest neighbors exchange more larvae with each other than with distant populations, *e.g.*, *S. atrovirens*. Refuges must be placed within the dispersal range of harvested areas to guarantee the re-supply of

adults, so a strategy of several small rather than few large refuges would be appropriate.

Obviously, variability in larval dispersal for *Sebastes* is key to the design of appropriate refuges, under the models proposed by Carr and Reed (1993). However, the selection of the number and size of refuges may also critically depend on the ability of the managing agency to enforce harvest restrictions, whether the zone is "no-take" or subject to harvest.

A range of 20 to 50 percent of habitat required for marine zones to serve as a functional management tactic was suggested above. There are too few studies of refuges to state minimum effective sizes for the inshore rockfish species complex. Regardless of the size of the refuges, a key issue relates to the overall harvest in the fishery after refuges are established. When a harvest refuge is established, the size of the harvestable population is reduced. It is critical not to compensate for the reduction in available biomass by increasing the harvest of unprotected populations. Indeed, the appropriate management action is to reduce the applicable quota by an amount proportional to the ratio of the size of the harvested area divided by the harvested plus refuge area (Polacheck 1990).

Marine protected areas could constitute a tactic for the strategy of preserving a minimum spawning biomass. Given the life history strategy of late maturation and investment of reproductive capacity in long-lived adults, the protection of populations with intact, unfished, age distributions may be as important as preserving a minimum spawning biomass. However, one of the most difficult problems in the adoption of marine zones as a fisheries management tactic is validating their performance in replenishing harvested areas. This task involves determining the relative contribution of recruits from refuges and requires long term monitoring of population size (if possible), age structure, size-specific fecundity, and recruitment. The latter is problematic for *Sebastes*, but progress in distinguishing spawning stocks might be made through the use of micro-satellite DNA techniques.

7.3 Experimental harvest strategies

Simulation modeling to examine the implications of harvest strategies for Pacific ocean perch was conducted by Archibald *et al.* (1983), Francis (1986), Hightower and Grossman (1987), Walters and Collie (1989), Ianelli and Heifitz (1995), and Richards *et al.* (1997). Apparently there are few other published studies of population modeling for *Sebastes* other than Pacific ocean perch, with the exception of modeling of *S. flavidus* stocks (Tagart *et al.* 1997, references therein). However, it is worth considering the conceptual basis for experimental approach advocated by Walters and Collie (1989) and that implemented by Leaman and Stanley (1993) for Pacific ocean perch.

Walters and Collie (1989) advocated an aggressive experimental approach comprised of (1) cooperative work with industry to exploit the ability of the fleet to sample rockfish density and distribution, and (2) planned, large-scale experiments to produce contrast in stock size to quantify the risk of recruitment failure. They assumed that a reliable abundance index can be measured on a (stratified) coast wide basis. However, see Leaman and Stanley (1993) for evidence that this assumption is extremely difficult to achieve. The proposal was to completely stratify the British Columbia coast by latitude into seven fishing zones including closed, free-fishing (high exploitation), and quota management areas (low exploitation). The proposed mixture of fishing zones along latitudinal gradients was thought to allow spatio-temporal variability in production to be exploited. The single closed area was intended to act as an insurance policy against the risk of biological extinction in other areas, rather than as an experimental control. The areas were spatially large to enable enforcement and to reduce the risk of potential stock movement confounding results. Implementation of the plan would require (1) coastwide surveys for measuring abundance trends, (2) contained, replicated experimental demonstration of the consequences of deregulated fishing, and (3) contingency plans to guide decisions in the event of marked declines in abundance.

In their simulations, Walters and Collie applied a harvest strategy designed to detect stock status within five years of high exploitation. Stocks in the free-fishing areas would be depleted to about 40 percent of their starting biomass to allow detection within the five year period. They acknowledge, however, that the ability to detect a change in abundance depends on survey precision (assumed to be 20% of mean survey CPUE) and on the actual exploitation rate. Lower precision and exploitation rates implied longer times to detect the change. The contingency plans to be invoked for remedial action were based on simulations to estimate the recovery from "severe declines" from various starting biomass values, over a 100 year horizon. Recovery was defined as the point at which equilibrium was achieved subject to a harvest calculated as biomass minus half of the unfished stock size. The harvest rate was constrained between a 0.01 minimum rate and the long term maximum sustained yield. Recovery times varied from about a decade under optimistic stock levels, several decades with moderate stock levels, and 90 years or more under low initial stock levels. Barring immediate stock collapse of free-fishing zones in the initial five years, Walters and Collie concluded that possible impacts on recruitment would not become evident for at least 10 years, and more likely for 20 to 30 years given the variable recruitment observed for Pacific ocean perch which recruit at ages 8 to 12. Although too lengthy to summarize here, Walters and Collie pursued a comprehensive decision analysis based their simulations, which could serve as an example for future simulation exercises for inshore rockfishes.

Potential problems for experimental harvest strategies as proposed by Walters and Collie include the following:

1. The situation for Pacific ocean perch was relatively clean, in the sense that essentially a single user group exploited the resource. With inshore rockfishes, however, various industry sectors, the recreational sector, and First Nations compete for the allocation of the resource either directly or through bycatch allowances.

- 2. The appropriate survey methodology for producing abundance indices for inshore rockfish species is unclear, although various methods have been tried including hook and line CPUE (Richards 1987, Richards and Hand 1987, Richards et al. 1988, Yamanaka and Richards 1993a), and direct observation using submersibles (Richards 1986a, O'Connell and Carlile 1993), video cameras and SCUBA (W. Palsson, pers. comm.). Indeed, even if trawl methods could be used for inshore species, estimates of stock indices may be unreliable for detecting anything other than large changes in biomass (Leaman and Stanley 1993).
- 3. The scale of the experimental areas does not recognize the suspected mechanism for depletion of inshore rockfish populations, which consists of the accumulated effects of small localized depletion. Surveys may not be sensitive to localized depletions until the depletion patch size becomes large.
- 4. There is a focus on experiments that kill fish to examine the effects of harvest, and admittedly, shed light on harvest-driven processes. Experimenting with harvest rate is a natural tool for fishers to propose, since it is a tool familiar to them. Biologists may also find it attractive, since a means of engaging fisherman in the experiment arises through fishing privilege or charter work. However, this orientation comes at the expense of experiments on spatial treatments (*e.g.* different sizes of protected areas) to examine production driven processes.

Experimental management has been applied to Pacific ocean perch off the west coast of Vancouver Island and at the Langara Spit region of Dixon Entrance (Leaman and Stanley 1993). Experimental harvest regimes were implemented in each area in partnership with the fishing industry to test the validity of biomass estimates from The west coast Vancouver Island standardized surveys and assessment models. experiment involved a three year period of over-fishing at a rate 67% greater than the estimated sustainable level. This initial fishing down period was followed by a return to sustainable harvest levels. Stock abundance indices over the course of the experiment showed declines consistent with a significant decline in biomass, as well as marked reduction in the catch rates in the commercial fishery. Analysis of size frequency indicated a total mortality of greater than four times the optimum level. There has been no reporting to date on whether the fishing experiment produced a detectable anomaly in the age composition of fish in the experimental area. Although industry cooperation was good for this experiment, no consensus on sustainable harvest levels was reached as a result of the experiment.

The Langara Spit experiment similarly implemented a period of prescribed overharvest with the objectives of validating trawl survey biomass estimates, developing estimates of fishing mortality, examining detailed records of fishing patterns, and probing the stock-recruitment relationship. In addition, detailed records of fishing vessel characteristics, catch and effort were gathered as a result of direct industry cooperation. Implementation problems with this study tempered its success (Leaman and Stanley 1993). However, both experiments did demonstrate that measurable and negative impacts on stock indices and biological parameters could result from the application of harvest rates in excess of estimated natural mortality (M=0.05 for S. alutus). In addition, the experiments raised concerns over the reliability of trawl survey methods for slope rockfishes. Specifically, strong evidence was provided that diel and tidal behavioral patterns can produce changes in CPUE of two orders of magnitude over the same 24 hour period at the same locality. This has sobering implications where survey observations are expanded over a large geographical scale. Similar concerns will have to be evaluated for inshore species, should standardized hook and line surveys be attempted.

7.4 Tenure rights

One alternative not considered to date by managers and industry is the adoption of an area-based tenure system for individual fishers or fishing cooperatives. Fishers could pay a fee to lease discrete fishing areas for a relatively long period of time. This may encourage husbandry of the resource, since individual fishers may have an interest in long term production from their turf, and in maintaining the value of the lease holdings, if transferable. Furthermore, a buyer of a lease would seek evidence that stocks in the lease holding have not been depleted below commercial sustainability, *i.e.* a stock assessment. Further examination of this approach in the literature may be warranted, particularly for relatively sedentary species such as rockfishes. The difficulty in this context is maintaining the exclusive rights of leaseholds in the face of, for example, recreational fishing pressure. Researchers working on the management of tropical reef fisheries are returning to such alternatives after rejecting traditional fisheries models such as catch at age and single species approaches (Polunin and Roberts 1996).

8. A Strategy for Reconciliation

A variety of traditional approaches have been used to manage and assess rockfishes, without much success (Leaman 1987). Commercial catch and effort data are difficult to interpret for the hook and line fishery because of changes in fishery participants (Yamanaka and Richards 1992), product demand associated with the burgeoning live market, on-board electronics, and a plethora of management tactics. Traditional stock assessment methods such as catch at age models, area-swept trawl surveys, acoustic surveys, and mark-recapture studies are inadequate for the assessment of inshore rockfishes because of a lack of requisite time-series data, and difficulties imposed by *Sebastes* habitat preference, and physiology.

Three components designed to reconcile management and assessment strategies for inshore rockfishes were suggested in Section 2.4. In review, these components included (1) pragmatic simulation modeling, (2) experimental manipulation on various scales, and (3) stakeholder participation. This section provides elaboration on each components in light of the preceding discussion.

8.1 Progress through pragmatic modeling

Experience to date for rockfishes suggests that the pursuit of traditional fisheries models by assessment biologists will not provide sufficient guidance for managers in the short term. Furthermore, the uncertainty about stock status for every species in the inshore rockfish complex will lead assessment biologists to recommend relatively low levels of harvest (Walters and Pearse 1996). The prospects for progress on basic biological research, the accumulation of biological samples, and the development of reliable assessment methodologies are not encouraging unless objectives are developed to provide guidance. The dilemma is that a management strategy is not immediately apparent given the difficulties posed by *Sebastes* life history and the data requirements of traditional fisheries models.

One means of breaking the impasse and reconciling the disparity between management and assessment is to initiate a pragmatic modeling approach for inshore rockfishes as described by Starfield (1997) and Starfield and Bleloch (1986). Starfield maintained that, in general, impasses may arise due to misconceptions that models are not useful when there are gaps in the data, or that a model cannot be used unless its accuracy is verified, or that a model cannot be built unless there is a complete understanding of the behavior of a system. In British Columbia, there has been little modeling of inshore rockfish populations in the context of evaluating management alternatives. Following the perspective of Starfield (1997), the paucity of data for inshore rockfishes should not preclude developing models, since the only means of determining what data are required, and how much data are needed, is to evaluate the data in the context of a model.

Starfield (1997) viewed a model as an experiment or problem solving tool rather than an accurate and verified representation of reality. The measure of a model's success is whether a better decision is made with the model, rather than if the model is accurate. He reviewed a number of misconceptions about modeling that discourage their adoption in wildlife management, and which have direct applicability to the problems posed by inshore rockfish management. A summary of the perspective on "pragmatic" modeling is listed below, although Starfield (1997) provides a more elegant presentation:

- 1. Management decisions inevitably are made without a complete understanding of a population, thus, a model represents the current best understanding of system function where the assumptions are explicit. If there are competing assumptions, then several alternative formulations of the model are required to examine the consequences of the assumptions.
- 2. Models are useful even when the data are incomplete. The model can be used to determine the effects of the missing data, or whether a particular management plan is sensitive to the missing data (Ralls and Starfield 1995). The model may offer guidance for collecting the data and the required resolution of the data.
- 3. When the model is viewed as a problem solving tool, its absolute accuracy and validity is not critical to its use. The model demonstrates the consequences of

assumptions and need only be internally consistent. Analyses should include verification that the model is being used correctly and interpreted in a sensible manner. The value of the model lies in what is learned about the consequences of the assumptions upon which the model is based.

- 4. The model need not be as detailed and realistic as possible if modeling is accepted as an experiment. Rockfish population dynamics will offer infinite, and probably unnecessary, detail. The leanest possible model should be developed, *i.e.* if alternative management plans are to be evaluated, then differences among the plans should determine what is included in the models.
- 5. A model serves to enable communication between assessment biologists and managers, industry stakeholders, and the public. A simple, easily understood model may be preferable to a more complex, but less understandable model. One advantage of a model for inshore rockfishes is that it may cause managers and stakeholders to expand the time horizon on which they think about the problem.
- 6. The importance of models may lie in what is learned in the process of designing and implementing them, rather than in the results or their ability to make predictions. This is not to say that models cannot make forecasts or projections.
- 7. Models do not have to be large and complex, *i.e.* different questions may require different simplifying assumptions. Large models are likely to be complex and "data hungry" whereas small simple models are easily understood and may be implemented where little data are available (however, for a counter-example, see Richards and Schnute 1995).

This perspective of models as a problem-solving tool may provide a vehicle for evaluating competing management strategies for inshore rockfishes. Significant progress in understanding the management constraints imposed by rockfishes has been established in conjunction with simulation exercises (*e.g.* Archibald *et al.* 1983, Francis 1986, Hightower and Grossman 1987, Learnan 1987, 1991, Walters and Collie 1989). For examples of situations in fisheries where a simplified model was determined to be superior to a complex model with more parameters, see Hilborn (1979), Ludwig and Hilborn (1983) and Ludwig and Walters (1985).

The opportunity that models provide for evaluating data collection programs cannot be ignored. Fisheries data are often collected for long periods without being analyzed or evaluated. Consider, for example, the commercial fish slip data collected from 1956 to 1995, which have proven weak for the assessment of inshore rockfishes. A stochastic model can be used to determine how much data would be required to compute, say, reproductive value, given current assumptions about fecundity and spatial variability in age distributions. One modeling scenario that should not be overlooked is to simulate the undisturbed population from a risk assessment perspective in order to quantify the probability of bad outcomes in the absence of fishing mortality. The key to the success of pragmatic modeling is dependent upon:

- 1. A lucid statement of objectives;
- 2. The definition of a set of measures or indicators for evaluating the degree to which objectives are achieved;
- 3. A procedure for ranking alternative strategies (a decision analysis) in terms of the defined indicators.

Operationally useful management objectives for the inshore rockfish fisheries in British Columbia have not evolved, in part due to operational constraints, and also due to the absence of appropriate assessment methodology. However, the precautionary approach to fisheries (FAO 1995) identified a role for assessment biologists in helping managers to define operational targets and biological objectives; simulation modeling is a vehicle for that collaboration.

8.2 Experimental manipulation and stakeholders

Experimental manipulation of inshore rockfishes is severely disadvantaged by the longevity of the species and late age of recruitment. The commitment required on the part of the managing agency and stakeholders is a long term proposition hard to maintain in the face of continuous demands for results and interpretation of experiments. The experience for *S. alutus* in British Columbia (Leaman and Stanley 1993) is that experimental manipulation is vulnerable to contamination by incorrect data (misreporting) and forces external to the experimental objectives (social economic considerations). As discussed earlier, a balance needs to be struck between experimentation that examines that effects of harvest only, versus manipulations directed at resolving production-based processes.

Other researchers have devoted considerable thought to the requirements for cooperative experimentation with stakeholders (see, for example, Walters and Collie 1989, Leaman and Stanley 1993, Walters and Pearse 1996). These requirements include:

- 1. Established indices and criteria for the interpretation of results agreed upon during the planning stages;
- 2. Involvement of stakeholders in the planning stages for experimentation and in frequent review of current status;
- 3. Agreed upon actions taken in response to changes in indices, prior to when the action is required, *i.e.* contingency plans;
- 4. Agreed upon requirements for data collection and validation, even if participants chose to leave the experimental protocol;

- 5. Commitment to a sufficiently long time frame so that institutional or stakeholder impatience does not compromise the experiments;
- 6. Education of managers and stakeholders about the scope of potential results prior to initiation of the experiments, and education of assessment biologists about the economic forces likely to arise as a result of the experimentation. For example, these forces may include increased capitalization and community dependence as a result of an unrestricted fishing program. Researchers need to be aware that the economic engine drives some of what is planned, and most of what is not planned.

The costs of experimentation are potentially significant to industry. For example, the cost of implementing a marine protected area directly affects industry since an immediate reduction in the TAC is required to compensate for the creation of the refuge. There are no obvious options for the assessment and management of inshore rockfishes that do not involve cost to industry. Managers can propose that experimental manipulation is a form of stakeholder investment. While there may be an institutional commitment to share in the benefits of investment in information, it is entirely possible for *Sebastes* that increased knowledge will imply more restrictive rather than greater catches. The incentives for investment in information by fishers have been discussed in the context of individual quota management by Walters and Pearse (1996).

For the most part, this paper has not focused on specific strategies such as individual transferable quotas (ITQs) because the problem of determining an allocation scheme among Zn fishers is far more tractable than determining stock status. However, there is currently discussion of ITQs with the hook and line industry. If ITQs are adopted, then assessment biologists and managers can anticipate a much greater demand on stock assessment activities than has been the case. Walters and Pearse (1996) provided a thorough treatment of the demands on stock assessment incurred by ITQ systems, and discussed avenues for encouraging investment in information by fishers. It is interesting to note that the ITQ proposal currently under consideration by Zn licensed fishers appears to place the onus on industry to regulate market supply and demand in the absence of trip limits, fishing options, fishing period catch limits, or other restrictions. Many of these tactics were originally endorsed by industry to regulate supply to the market, rather than to achieve specific conservation objectives for rockfish stocks. The potential impact of ITQs on fishery dependent indices for rockfishes is uncertain.

8.3 **Recommendations**

The proposal in this paper is to base progress on reconciling assessment and management of inshore rockfish upon a foundation of carefully developed simulation modeling. The suggestion is that simulations be viewed as a vehicle for communication and learning about the consequences of model assumptions. The answer to the question of what specific strategies should be considered is dependent to a large degree on the outcomes of simulation work, but some initial avenues for investigation are provided in the list of recommendations. These possibilities involve a combination of large scale experimentation on harvest strategies coupled with tools designed to investigate production-driven processes, such as marine zones. Also included are recommendations specific to some shortcomings of current practice in data collection and management, with a view to improving the long term accumulation of data.

Combined Assessment and Management Recommendations

- 1. Initiate the development of a working set of objectives for assessment and management of inshore rockfishes. In order to develop strategies and identify tactics, an operationally useful set of objectives is required. A natural outcome of this exercise will be to identify what data are lacking to achieve the objectives. This in turn will prime the modeling process. The process may require several iterations, and may involve assessment staff, fishery managers and stakeholders.
- 2. Develop plans for large scale experimentation based on simulation modeling. A balance should be struck between experiments that investigate harvest driven processes by considering alternative levels of fishing, and programs that examine production-driven processes by, for example, implementing spatially replicated refuges of various sizes. Simulations should consider stock indices based on life history, such as reproductive value. These plans might be modeled after the example provided for Pacific ocean perch by Walters and Collie (1989), but suitably tailored for inshore rockfishes.
- 3. Develop plans for small scale experimentation to examine localized effects of management manipulation. These experiments could provide information on seasonal migration, responses to fishing mortality, and evaluation of the effects of establishing refuges all scaled to the realities of current resource levels. Such work can provide information used to refine the assumptions of simulation modeling of larger-scale programs.

Research Recommendations

- 1. Investigate remote-sensing technologies applicable to inshore rockfishes such as acoustic techniques for habitat mapping and video sampling methods. Exchange of technology and information should be sought with Alaska and Washington states on sidescan sonar technology, video acoustic sampling, and the work on marine protected areas in Puget Sound.
- 2. Continue basic research on the reproductive biology of inshore rockfishes. Field programs (fishery independent) are required to determine temporal variability in fecundity, age composition, larval production, growth, genetics, *etc.* In particular, data collection should accommodate the computation of stock indices based on life history (*e.g.* reproductive value). Some of this work can be done in cooperation with stakeholders who can provide research platforms, samples, and knowledge of fish distribution and co-occurrence.

- 3. Implement a program for systematic biological sampling of the commercial catch. There is currently no representative sampling from commercial catch to obtain biological data such as length, weight, sex, maturity, and age from commercial landings.
- 4. Yield recommendations should be provided for a period of years. In concert with the management recommendation, there is no reason to continually adjust recommended catch in minor ways. This practice should be subject to contingency plans when there are indications of negative stock impacts (*e.g.* decline in abundance, aberrant age composition, localized depletion).

Management Recommendations

- 1. Extend the planning horizon for the management of rockfishes from an annual activity to a half decade or decade time horizon. Stability in management tactics is a key requirement to reducing confounding influences on commercial catch and effort data and experimental manipulation. For species with generation times on the order of two to three decades and lifespans of 50 to 100 years, there is little biological or conservation advantage to continual adjustment to management tactics. This is not to say contingencies should not be built into the longer planning horizon to allow intervention when appropriate.
- 2. Quotas should not be set for large regions to reduce the risks of hyperstability of catch per unit effort. Even if there is currently no basis for sustainability within smaller areas, the chances of detecting changes in fishery indices, and limiting the effects of excessive harvest, increase as the size of the management unit decreases.
- 3. A corporate record of management strategies and tactics must be established and maintained. A single generation cycle for rockfish species can require the working careers of several managers. Thus, the development of long term management programs for rockfishes requires a detailed corporate record of strategies and tactics. The current Fishery Management Plans do not contain sufficient detail of what actually happened, as opposed to what was planned. The discrepancy is due to in-season adjustments to the plan which are not formally documented. This documentation is crucial to the interpretation of stock assessment data and to reconstructing the management history of stocks.

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Appendix 1 Management tactics for the "Inside" Rockfish Fishery

Year	Management Tactics
<1986	No restrictions on commercial fishing
1986	Implementation of the Zn Licenced fishery
	 1362 vessels licensed coast wide
•	Logbooks:
	 logbook program implemented
	Fixed season closure:
	• 15 Feb to 15 Apr
1987	• 1935 vessels licensed coast wide
	Fixed season closure:
	• 01 Jan to 15 Apr
	TAC:
	• 75 t quota in area 12 under permit
1988	 2105 vessels licensed coast wide
	Fixed season closure:
	• 01 Jan to 30 Apr
	Area closure:
	• subareas 13-2 to 13-9, 13-11, 13-27
1989	• 2319 vessels licensed coast wide
	Fixed season closure:
	• 01 Jan to 30 Apr
	Area closure:
	• subareas 13-2 to 13-9, 13-11, 13-27
1990	 2396 vessels licensed coast wide
	Fixed season closure:
	• 01 Jan to 30 Apr and 01 Nov to 31 Dec
	Area closure:
	• subareas 13-2 to 13-9, 13-11, 13-27
1991	Zn area licensing
	• 592 vessels licensed inside
	Fixed season closure:
	• 01 Jan to 14 May
	Area closure
1	• subareas $13-2$ to $13-9$, $13-11$, $13-27$
1	• UK quota 300 t.

1992	Limited entry:
	• 74 vessels licensed
	Fixed season closure:
	• 01 Jan to 30 Jun
	Catch-limited opening:
	• 01 Jul to 06 Sep
	• 29 Sep to 13 Dec (OR), 31 Dec (YE)
	Area closure:
	• subareas 13-2 to 13-9, 13-11, 13-27
	TAC:
	• YE quota 59 t
	• OR quota 130 t
1993	Limited entry:
	• 74 vessels licensed
	Catch-limited opening:
	• YE opened 01 Jan until 20 t landed
	• 15 Jun to YE and OR quota attained
	Area closure:
	• subareas 13-2, 13-9, 13-11, 13-27
	TAC:
	• YE quota 70 t
	OR quota 140 t
1994	Limited entry:
	• 74 vessels licensed
	Logbooks:
	logbooks revised
	user-pay program implemented
	Fixed season closure:
	• 01 Jan to 14 Jun, but see catch-limited openings
	Catch-limited opening:
	• YE 01 Jan until 20 t landed, 15 Jun for balance of YE TAC
	OR 15 Jun until 140 t, 01 Dec for balance of OR TAC
	Area closure:
	• subareas 13-2 to 13-9, 13-11,13.27, 14-11, 14-14, 16-3, 16-4, 17-7, 17-
ļ	14, 17-20, 17-21, 18-8, 19-1, 19-6, 19-7 to 19-12, 20-6, 20-7, 28, 29-7
	to 29-17
1	• YE quota /0 t
	• OR quota 150 t
1	Live tish policy:
L	• minimum 80% live landings (pieces) of all rockfish species except YE

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1995	Limited entry:
	 74 vessels licensed
	Dockside monitoring of landings:
	 user pay validation for all landings of Zn license holders
	Fixed season closure:
	• 01 Jan to 14 Jun
	Area closure:
	• subareas 13-2 to 13-9, 13-11 and 13-27
	Aggregate management:
,	• catch managed using species aggregates
	TAC:
	• YE quota 62 t (32 t directed fishing, YE catch thereafter combined with
	A2 to A6 bycatch to a maximum of 20% of A1 per landing)
	• A1, A2 combined quota 150 t
	Fishing period catch limits:
	• 3,500 lb. A1 per fishing period
	• 6000 lb. YE per fishing period
	• A2 to A6 bycatch limited to 20% of A1 and YE by round weight per
	landing
	• overage of A1 up to a maximum of 20% per fishing period is deducted
	from the vessel's next fishing period
	• no restrictions on the number of rockfish landings per fishing period
1996	Limited entry:
	• 70 vessels licensed
	Dockside monitoring of landings:
	• user pay validation for all landings of Zn license holders
	Fixed season closure:
	• 01 Jan to 14 Jun
	Area closure:
	• subareas 13-2 to 13-9, 13-11, 13-27, 14-11, 14-14, 16-3, 16-4, 17-7, 17-14,
	17-20, 17-21, 18-18, 19-1, 19-6, 19-7 to 19-12, 20-6, 20-7, 28, 29-7 to
	29-17
	Aggregate management:
	 species composition of aggregates revised
	TAC:
	• YE quota 26 t directed fishing (bycatch limited to 20% of A1 per
	landing thereafter)
	• A1, A2 quota 150 t
	Fishing period catch limits:
	• 1,800 lb. A1 per fishing period
	• 600 lb. A2 to A7 combined per fishing period
	• 2,500 lb. YE per fishing period
	• overage on each of A1, A2-A7 combined, YE up to a maximum of 10%
	per fishing period is deducted from the vessel's next fishing period
Į	• no restriction on the number of landings per period

1997	Limited entry:
	• approx. 70 vessels licensed
	Dockside monitoring of landings:
	• user pay validation for all landings of Zn license holders
	Fixed season closure:
	• 01 Jan to 14 Jun
	Area closure:
	• Sub-areas 13-2 to 13-9, 13-11, 13-27, 14-11,14-14,16-3,16-4,17-7,17-
	14, 17-20, 17-21, 18-18, 19-1, 19-6, 19-7 to19-12, 20-6, 20-7, 28, 29-7
	to 29-17
	TAC:
	• YE 24 t directed fishing (bycatch limited to 20% of A1 per landing
	thereafter
	• A1,A2 quota 143 t
	Fishing period catch limits:
	• 1,500 lb. A1 per fishing period
	• 600 lb. A2-A7 combined per fishing period
	• 2,500 lb. YE per fishing period
	• overage on each of A1, A2-A7 combined, and YE up to a maximum of
	10% per fishing period is deducted from the vessel's next fishing period
	• no restriction on the number of landings per period

Appendix 2 Management tactics for the "Outside" Rockfish Fishery

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Year	Management Tactics
<1986	No restrictions on commercial fishing
1986	Implementation of the Zn Licenced fishery
	• 1362 vessels licensed coast wide
	Logbooks:
	 logbook program implemented
1987	No restrictions on commercial fishing
to	• 1935 vessels licensed coast wide in 1987
1989	 2105 vessels licensed coast wide in 1988
	 2319 vessels licensed coast wide in 1989
1990	 2396 vessels licensed coast wide
1	TAC
ļ	 NC, CC, QCI, WCVI total quota of 650t rockfish
	Area closure:
	• CC: portions of area 7 closed
	WCVI: inside surfline closed 01 Jan to 30 Apr
1991	Zn area licensing
	• 1595 vessels licensed outside
	Fixed season closure:
	NC, CC, QCI: open 01 Jan
	Area closure
	• NC: rotational closure introduced in area 7
	• WCVI: inside surfline closed 01 Jan to 30 Apr
	TAC:
	• NC: YE 80t, OR 20t (quotas achieved 05 Aug)
1	• QCI: YE 200t, OR 100t (quotas achieved 11 Sept)
	• CC: YE 100t, OR 100t (quotas achieved 06 Jul)
1002	WUVI: YE 250t, UK 150t (quotas achieved 10 Dec)
1992	Le area licensing
	• 1223 vessels licensed outside
	rixed season closure:
	• INC: CIOSED UT JAIN 10 10 JAIN
	Area crosure.
	WCVI: inside surfline closed 01 Ian to 30 Apr
	TAC
	• NC: YE 80t, OR 20t (OR quota achieved 05 Jun, YE open in subareas 103-
1	105 until 31 Dec, 72t taken)
1	• OCI: YE 200t, OR 100t (YE quota achieved 02 Jul, OR open to 31 Dec, 47t
	taken)
	• CC: YE 100t, OR 100t (YE quota achieved 17 May, OR quota achieved 08
	May)
1	 WCVI: YE 250t, OR 150t (quotas achieved 27 Jul)

1993	Limited entry:
	 implemented, 183 license holders
	Area closure:
	WCVI closed 01 Jan to 30 Apr
	• rotational closure in area 7: areas 7-1, 7-2, 7-17 to 7-24, and 7-32 open
	Catch-limited opening:
	• open 01 Jan to first of 15 Jun or until 66% TAC taken
	• open 15 Sep to first of 31 Dec or until balance of TAC taken
	TAC:
	• NC: YE 80t, OR 20t
	• QCI: YE 200t, OR 100t (66% YE achieved 30 Apr)
	• CC: YE 100t, OR 100t (66% achieved 04 Apr)
	WCVI: YE 250t, OR 150t (OR quota achieved 21 Aug)
1994	Limited entry:
	• 181 vessels licensed
	Logbooks:
	logbooks revised
	• user-pay program implemented
	Fixed season closure:
	• WCVI: closed 01 Jan to 14 Apr
	Catch-limited opening:
	• QCI: YE open 01 Jan to first of 15 Jun of 66% of quota achieved, open for
	balance of quota 15 Sep
	• NC: YE, OR open of Jan to 15 Juli of ultimot % of quota achieved, open for
	CC: VE OP open 01 Jap to 15 Jup or until 66% of quota achieved open for
	balance of quota 01 Nov
	NC CC: when VF or OR quota attains 66% of quota, the other quota will
	close the first of 15 Jun or when quota is within 10% of the 66% cutoff
	Area closure:
	• rotational closure in area 7: areas 7-3 to 7-16 and 7-29 to 7-31 open
	WCVI: Swiftsure closure
	TAC:
	• OCI: YE 200t, OR 54t
	• NC: YE 60t, OR 60t
	• CC: YE 100t. OR 100t
	• WCVI: YE 200t, OR 150t
	Trip limits:
	• combined POP, YE, RS 4.5 tonnes (~10,000 lb)
	• combined CA, SG 4.5 tonnes (~10,000 lb)
1	• combined YE, WI 4.5 tonnes (~10,000 lb)
	• combined RE, ST, Idiots 6.8 tonnes (~15,000 lb)
1995	Limited entry:
	• 183 vessels licensed
1	Dockside monitoring of landings:
	• user pay validation for all landings of Zn license holders
	Fixed season closure:
	WCVI: closed 01 Jan to 14 Apr
	Catch limited opening:

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	• QCI, NC, CC, WCVI: when 90% of the YE quota has been taken in any one	
	management area, all waters outside the surfline will close (balance of YE	
	quota available inside surfline as bycatch for directed fishing on A1+A2)	
	• QCI, NC, CC, WCVI: when 90% of the A1+A2 quota has been taken in any	
	one management area, all waters inside the surfline will close (balance of YE	
	quota available outside the surfline as bycatch for directed fishing on YE)	
	Area closure:	
	 subareas 13-2 to 13-9, 13-11 and 13-27 	
	 rotational closure in area 7: subareas 7-25 to 7-28 open 	1
	Aggregate management:	
	 catch managed using YE and 6 species aggregates 	
	TAC:	
	• QCI: YE 189 t, A1+A2 50t	
	• NC: YE 47 t, A1+A2 60t	ļ
	 CC: YE 100t, A1+A2 100t 	1
	 WCVI: YE 195t, A1+A2 135t 	
	• A3 8,925t coast wide	
	 A4 735t coast wide (RE only, no quota on ST or Idiots) 	
	• A5 8,522t coast wide	
	 A6 no quota 	
	Fishing options:	
	• Option A:	
	 directed fishing A1 per fishing period 	
	 an allowance of YE, A2 to A6 per landing 	
	• restricted to a maximum of 4 landings of any rockfish each fishing perio	d
	• Option B	
	• directed fishing on A3 to A6 combined per fishing trip	
	 allowance of A1, A2, and YE combined per landing 	
	 restricted 4 landings of any rockfish per fishing period 	
	• Option C	
	• directed fishing on A3-A7 per fishing period	
	• by-catch allowance of A1,A2,YE combined per landing	
	 restricted 4 landings of any rockfish per fishing period 	
	Fishing period catch limits:	
	• Option A	
	• 7,000 lb. A1 per fishing period	
	 a quantity of A2 and YE combined < 50% of A1 per landing 	
	 a quantity of A3 to A6 combined < A1 per landing 	1
•	• a quantity A2-A5, A7 combined < 100% of total A1 per landing	
	• overage on each of A1 and A6 combined to a maximum of 10% per	
	fishing period is deducted from the vessel's next fishing period	
	• no restriction on the number of landings per period	
	• Ontion B	
	• 4.000 lb A1. A2 and YE combined per fishing period	
	• a quantity A3 to A6 combined < 150% of A1, A2 and YE combined per	
	landing	
	 restricted to 4 landings of any rockfish per fishing period 	
	Ontion C	

	• trip limit quantities of A3 to A6 per landing:
1	A3: 10,000 lb
	A4: 15,000 lb
	A5: 15,000 lb
	A6: 10,000 lb
	• a quantity of A1, A2, and YE combined not to exceed 10% of A3 to A6
	combined per landing
	restricted to 4 landings of any rockfish per fishing period
1996	Limited entry:
	• 183 vessels licensed
	Dockside monitoring of landings:
	• user pay validation for all landings of Zn license holders
	• inclusion of lingcod and dogfish
	Fixed season closure:
	• WCVI closed 01 Jan to 31 Apr
	Catch limited opening:
	• CC: 01 Jan until 60t taken; re-open 01 Nov for balance of quota
	• Option A vessels restricted access to area when 90% of A1+A2 taken
	• Option B vessels restricted access to area when 90% of YE taken
	Area closure:
	• CC: rotational closure in area /: subareas /-1, /-2, /-1/ to /-24 and /-32
·	open
	• WCVI: Swiftsure closure
	Aggregate management:
	• species composition of aggregates revised to include TE and 7 species
	• OCI: $YE 135t A1+A2 43t$
	• NC: $YF 38t A1+A2 62t$
	• CC: YE 119t A1+A2 116t (open 01 Jan until 60% A1+A2 taken re-open 01
	Nov for remaining 40%)
	• WCVI: YE 155t. A1+A2 152t
	• A3 1.813t coast-wide
	• A4 1.794t coast-wide
	• A5 6.585t coast-wide
	• A6 6.725t coast-wide
	• A7 monthly limit
	Fishing options:
	Option A:
	directed fishing A1 per fishing period
	• an allowance of A6 per fishing period
	• an allowance of A2 to A5, and A7 combined per landing
	• no restriction on the number of rockfish landings per fishing period
	Option B
	directed fishing on YE per fishing period
	allowance of A1 per landing
	allowance of A2 to A7 combined per landing
	• no restriction on the number of rockfish landings per fishing period
1	Option C

	 directed fishing on A3-A7 per fishing period
	 by-catch allowance of A1,A2 and YE combined per landing
	 no restriction on the number of rockfish landings per fishing period
	Fishing period catch limits:
	• Option A
	 2,500 lb. A1 per fishing period
	• 500 lb A6 per fishing period
	• a quantity of YE < 50% of A1 per landing
	• a quantity of A3 to A6 combined < A1 per landing
	• a quantity A2-A5, A7 combined < 100% of total A1 per landing
	• overage on each of A1 and A6 combined to a maximum of 10% per
	fishing period is deducted from the vessel's next fishing period
	no restriction on the number of landings per period
	• Ontion B
	a 3 000 lb VF combined per fishing period
	s = 3,000 is $12 combined per histing period$
	a quantity of A2 to A7 combined $\leq 100\%$ VF per landing
	a quantity of A2 to A7 combined < 10076 TE per landing
	• Overage of TE < 20% per fishing period is deducted from the vesser's
	next listing period
	• restricted to 4 landings of any rockrish per fishing period
	• Uption C
	• fishing period limits that vary depending on now much quota has been
	taken: $A_{2} = C 000 \text{ lb} (< 80\% \text{ TAC}) + 000 \text{ lb} (80 + 100\% \text{ TAC})$
	A3: $5,000 \text{ ID} (< 80\% \text{ IAC}), 1,000 \text{ ID} (80-100\% \text{ IAC})$
	A4: $(,500 \text{ ID} (< 80\% \text{ IAC}), 1,000 \text{ ID} (80-100\% \text{ IAC})$
	AS: $0,000 \text{ ID}$ (<80% TAC), 1,000 ID (00^{-100} /0 TAC)
	A0+A7. 10,000 10 (<0070 1AC), 1,000 10 (00-10070) 1AC
	fiching period shall be deducted from the vessel's next fishing period
1007	I imited ontaria
1997	Limited entry:
	• approx. 185 vessels licensed Decloride monitoring of landings:
	Dockside momenting of landings of 7n license holders
	• user pay validation for an fandings of 21 needs notices
	• Inclusion of Ingcod, dogrish, pacific cod, skale, sole, flounder
	Fined season closure.
	Area closure.
	• area / under rotational closure, subareas /-1, /-2, /-1/ to /-20, /-52 closed
	• WCVI open in areas $11, 21, 25-27, 111, 125-127, 12-14, 20-1 to 20-5, 121-122, 120, 1 mortions of 121, 1, 121, 2 (Swiftsure closure)$
	TAC:
	1 AC
	$ DP \cdot VE 36t \Delta 1 + \Delta 2 50t $
	• FR. TE 501, AT A2 551 • CO: VE 112t A1+A2 110t (open until 60% A1+A2 taken re-open 01 Nov for
	• U. IE II2, AITAZ II0 (open unit $00/0$ AITAZ taken, te-open of $100/10$
1	$= WCVI \cdot VE 140t A 1 + A 2 140t$
	• $VV \cup VI$. IE 1401, A1 A2 1401 - Coort wide: A2 2417t A4 2648t A5 10 563t A6 7 501 t A7 monthly limit
1	• Coast wide: A5 2417t, A4 2040t, A5 10,505t, A0 7,571 t, A7 monthly mint
	• NOTE: Species limits applicable within aggregates.
1	risning options:

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• Option A:
 directed fishing A1 per fishing period
• an allowance of A6 per fishing period
 allowance of A2-A5, A7 combined per landing
allowance of YE per landing
• no restriction on number of landings each fishing period
Option B
• directed fishing on YE under fishing period limit
• allowance of A1 per landing
• allowance of A2-A7 combined per landing
• no restriction on the number of rockfish landings per fishing period
Option C
• directed fishing on A3-A7 per fishing period
 by-catch allowance of A1,A2,YE combined per landing
• no restriction on the number of rockfish landings per fishing period
Fishing period catch limits:
Option A
• 3,000 lb. A1 per fishing period in Jan and Feb
• 2,000 lb A1 per fishing period Mar to Dec
• 500 lb. A6 combined fishing period
• a quantity of YE < 35% of total A1 per landing
• a quantity A2-A5, A7 combined < 100% of total A1 per landing
• overage on each of A1 and A6 combined to a maximum of 10% per
fishing period is deducted from the vessel's next fishing period
• no restriction on the number of landings per period
Option B
• 3,000 lb YE per fishing period
• a quantity of A1 < 20% of the YE per landing
• a quantity A2-A7 combined < 100% of the YE per landing
• overage of YE up to a maximum of 20% per fishing period is deducted
from the vessel's next fishing period
 no restriction on number of landings per fishing period
Option C
• fishing period limits that vary depending on how much quota has been
taken:
A3: 5,000 lb (<80% TAC), 1,000 lb (80-100% TAC)
A4: 12,000 lb (<80% TAC), 1,000 lb (80-100% TAC)
A5: 6,000 lb (<80% TAC), 1,000 lb (80-100% TAC)
A6+A7: 10,000 lb (<80% TAC), 1,000 lb (80-100%)TAC
• a quantity of A1, A2, and YE combined not to exceed 14% of A3-A5, A7
combined per landing

Appendix 3 Performance of Marine Protected Areas in Puget Sound

One study specific to rockfishes examined the performance of harvest refuges established in Puget Sound since at least 1990, and as long ago as 1970 in the case of the Edmunds Park MPA (Palsson and Pacunski 1995). Harvest was excluded from the Puget Sound sites to protect marine fishes and invertebrates from recreational and commercial removals. Monitoring surveys designed to contrast two refuge sites with five actively fished sites were conducted in 1992 and 1993. The results presented in the paper are confined to copper rockfish (*S. carinus*), quillback rockfish (*S. maliger*), and lingcod (*Ophiodon elongatus*).

Dive surveys were conducted using strip transect (rockfishes) or line transect (lingcod) methods at each of seven study sites. For each transect, the number of fish by species was recorded as well as a visual estimate of the length of each fish to the nearest 10 cm interval. The weight of each fish was estimated using length-weight relationships for each species; biomass per transect was estimated as the sum of the estimated weights. Similarly, the number of eggs produced per transect was estimated by a length-fecundity relationship for each species. The total number of eggs was computed by summing estimates for individual fish and dividing by two to adjust for an assumed 1:1 sex ratio.

Surveys of the Edmunds Park site showed a greater density and higher frequency of large copper rockfish than was observed at the other six sites, including the other refuge site at Shady Cove. In contrast, the density of quillback rockfish at Boeing Creek (a fished site) was about twice that within the Edmunds Park refuge site. Quillback rockfish larger than 40cm length were more numerous at the Edmunds Park site than elsewhere. Thus, the results for quillback rockfish are somewhat less clear than those reported for copper rockfish with respect to the effectiveness of the refuge areas. Other species surveyed, such as Puget Sound rockfish (*S. emphaeus*) and surfperches, showed lower abundance inside the protected areas (Palsson, pers. comm.). Indeed, the authors note three other studies where the abundance of some species did not change after establishment of a refuge.

Reported differences in reproductive output (number of eggs) were not surprising given the significant differences in rockfish size. Since the number of eggs per transect was computed from a length-fecundity curve, observed differences in size translate directly into differences in egg production. In general, fecundity increases with body size, so larger fish tend to produce more eggs. While it is reasonable to expect greater egg production from larger fish, there is no guarantee that increased egg output will translate directly into increased recruitment, inside or outside the refuge area. The authors identify fish movement, age of the refuge, inadequate sampling, visual detection problems, and differences in habitat as possible factors that affect the observed differences (or lack thereof).