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Abundance-Based Index Assessment Options for Dungeness Crab, (*Cancer magister*) and Spot Prawn, (*Pandalus platyceros*)

Méthodes d'évaluation des indices d'abondance pour le crabe dormeur *(Cancer magister)* et la crevette tachetée *(Pandalus platyceros)*

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Table of Contents

List of Tables

List of Figures

ABSTRACT

Allocation issues are especially prevalent for Dungeness crabs (*Cancer magister*) and prawns (*Pandalus platyceros*) because they are economically and socially important species. Periodically, Department of Fisheries and Oceans (DFO) resource managers in the Pacific Region receive undefined requests from First Nations for improved access to shellfish for food, social and ceremonial purposes. In most cases, there is little information available on local stock abundance to guide decisions and often, requests are met through effort limitations of the commercial fishing industry such as commercial area closures, seasonal closures or gear limitations.

Canada, British Columbia (B.C.), and First Nations are working to develop treaties, which clearly define the rights for First Nations, via a negotiation process. Numerous First Nations have expressed interest in abundance-based allocations for Dungeness crab and prawn species; however, the current management and assessment frameworks for Dungeness crab and prawn fisheries in British Columbia do not rely on abundance estimates and the data to support an abundance-based approach are lacking.

This paper evaluates the utility of historical catch as a means for delivering allocations for Dungeness crabs and prawns. We also describe fishery dependent and fishery independent CPUE (catch per unit effort) as indices of abundance and describe how allocations can be delivered from abundance indices for Dungeness crabs and prawns. Other abundance estimation models such as change-in-ratio, index-removal, mark-recapture and video assessment are presented.

For comparative purposes, we reviewed the Washington State models for allocation of Dungeness crab and prawn resources.

We conclude that historical catch information for Dungeness crabs and prawns are incomplete. We also conclude that final determination of the most successful approach will depend largely on the spatial scale, stock characteristics, dynamics of each fisheries sector, testing of assumptions and cost.

We provide the following recommendations:

1) Improve and develop catch monitoring programs for all Dungeness crab and prawn fisheries (commercial, recreational and First Nation FSC).

2) If abundance-based index methods are considered, then multiple programs should be initiated, developed and tested to determine which methods are most appropriate in each area prior to implementation of treaties.

RÉSUMÉ

Les questions d'allocation sont particulièrement d'actualité dans le cas du crabe dormeur (*Cancer magister*) et de la crevette tachetée (*Pandalus platyceros*), car il s'agit d'espèces d'une grande importance économique et sociale. Les gestionnaires des ressources du ministère des Pêches et Océans (MPO) ont reçu des demandes non définies de la part des Premières nations visant un accès accru aux mollusques et crustacés aux fins d'alimentation et d'activités sociales et cérémoniales. Dans la plupart des cas, il existe peu d'information sur l'abondance des stocks qui puisse guider les décisions et, souvent, les demandes sont satisfaites grâce à des limites de l'effort de pêche imposées à l'industrie de la pêche commerciale, telles que des fermetures de certaines zones à la pêche commerciale, des fermetures saisonnières et des restrictions liées au matériel.

Le Canada, la Colombie-Britannique et les Premières nations travaillent à mettre sur pied des traités qui définiront clairement les droits des Premières nations, au moyen d'un processus de négociation. De nombreuses Premières nations ont exprimé un intérêt envers les allocations fondées sur l'abondance dans le cas du crabe dormeur et de la crevette. Cependant, les cadres actuels de gestion et d'évaluation des lieux de pêche du crabe dormeur et de la crevette en Colombie-Britannique ne reposent pas sur des estimations d'abondance, et les données nécessaires à une méthode fondée sur l'abondance sont insuffisantes.

Ce document évalue l'utilité de l'historique des prises pour déterminer les allocations de ressources en crabe dormeur et en crevette. Nous décrivons également les captures par unité d'effort (CPUE), dépendantes de la pêche et indépendantes de la pêche, en tant qu'indices d'abondance, ainsi que la façon dont les allocations peuvent être dérivées des indices d'abondance pour le crabe dormeur et la crevette. On présente également d'autres modèles d'estimation de l'abondance tels que le changement du ratio, le prélèvement, le marquage-recapture et l'évaluation vidéo.

Nous avons examiné les modèles de l'État de Washington pour l'allocation des ressources en crabe dormeur et en crevette, à des fins de comparaison.

Nous concluons que l'historique des prises est incomplet pour ces espèces. Nous estimons également que la décision finale de la meilleure méthode dépendra en grande partie de l'échelle spatiale, des caractéristiques des stocks, de la dynamique de chaque secteur de pêche, de la mise à l'essai des hypothèses et du coût.

Nous soumettons les recommandations suivantes :

1) Améliorer et développer les programmes de surveillance des prises pour l'ensemble de la pêche au crabe dormeur et à la crevette (commerciale, récréative et CDF des Premières nations).

2) Si l'on opte pour des indices d'abondance, des programmes multiples devraient être lancés, développés et mis à l'essai afin de déterminer les méthodes les plus appropriées dans chaque secteur avant la mise en œuvre de tout traité.

Introduction

Fisheries for Dungeness crab (*Cancer magister*) have long been important in British Columbia (B.C.), with aboriginal harvests pre-dating European contact while prawn[1] (*Pandalus platyceros*) fisheries are more recently developed (Boutillier 1986; Butler 1984, 1986). Dungeness crab and prawn fisheries are economically and socially important species to commercial, recreational and First Nations fishing sectors. In 2003, for all wild shellfish fisheries, Dungeness crabs ranked first in total landings and landed value while prawns ranked 3rd in total landings and landed value (MAFF 2003). Since 1980, Dungeness crab commercial landings have ranged from 957 t in 1983 to 6,289 t in 1993 (Table 1). Although landings in most management areas increased over this period, fishery production has been primarily driven by Crab Management Area A (Figure 1) with smaller contributions from the other six Crab Management Areas. Coast-wide prawn fishery landings steadily increased from 320 t in 1982 to 1,785 t in 1997, and were above 1,700 t to 2001, with the exception of 1999 (Table 2). Most landings are from the East Coast of Vancouver Island, Pacific Fisheries Management Areas (PFMA) 12-19, 28 and 29 (Figure 2), with smaller contributions from the west coast of Vancouver Island and the northern coast of B.C.

Increasing demand and competition by all sectors for resources such as Dungeness crabs and prawns are well known. In Canada, consistent with the Supreme Court of Canada decision in the R. v Sparrow (1990) case, and the Department of Fisheries and Oceans (DFO) Policy for the Management of Aboriginal Fishing, aboriginal fishing for food, social and ceremonial (FSC) purposes has first priority, after conservation, over other user groups. Periodically, resource managers receive requests from First Nations for improved access to shellfish for FSC purposes. In many cases, expectations by First Nations are high and there is little information available on local stock abundance to guide decisions. Generally, management actions to provide improved FSC access are met through effort limitations such as commercial area closures, seasonal closures or gear limitations. Allocation issues are especially prevalent for Dungeness crabs and prawns because they are highly sought after, but there are currently no abundance estimates for these species.

The governments of Canada and British Columbia are negotiating treaties with First Nations with the objective of bringing certainty to issues of land ownership, taxation, and management of lands and resources (INAC 2004). Fisheries resources are of great importance to First Nations in the Pacific region and an important component of treaty fisheries chapters. For species or stocks that are highly sought after, DFO negotiates allocations that specify the amount of fish a First Nation may harvest in a given year. Fish allocations in treaties can be developed using three general approaches: fixed quotas, abundance-based formulas, or exclusive First Nations access areas (set-aside areas). The approach varies from species to species, and may also vary between First Nations for any given species

For species without abundance estimates, the simplest and least expensive option available is to establish fixed quotas based on historical catch data, however, there are risks and problems associated with this. Quota options for the commercial prawn fishery has been explored in BC but were found to present higher risk of recruitment over-fishing

[1] Other common names for *Pandalus platyceros* include spot prawn and spot shrimp; the latter is routinely used in Washington State. We use the common name prawn in this paper as the name has long been used by DFO, fishers and the general public (Butler 1980).

and would be expensive to implement considering data and analytical requirements (Boutillier and Bond 1999a). However, we propose the use of abundance indices as an alternative for delivery of allocation under treaties for Dungeness crabs and prawns. We believe this is possible given the small, discrete areas that treaties work under.

The objectives of this paper are:

1. To present abundance-based index methods for Dungeness crabs and prawns; and
2. To define data requirements and present other considerations for the potential options.

The paper will describe the problems and risks associated with using historical catch data for allocating quotas. We will then describe abundance index methods for Dungeness crabs and prawns on small spatial scales, and compare the benefits and disadvantages of each approach (Appendix 1).

Current Assessment and Management Frameworks

Dungeness Crabs

High natural variability in crab populations decreases the effectiveness of annual assessment programs in support of fishery management in British Columbia. Dungeness crabs are managed to prevent recruitment overfishing through a combination of size limits (the current minimum legal size is 165 mm measured across the carapace from point to point [CW]); sex restrictions (commercial fishers can only retain males ≥165 mm CW; release of females ≥165 mm CW is voluntary for First Nations and recreational fishers); seasonal closures during periods of moulting; non-retention of soft-shell crabs; and escape ports to allow juvenile crabs to escape (DFO 2005). Other objectives to manage commercial effort include trap limits, area-based licensing, and gear restrictions such as, rot cords to limit ghost fishing.

Fishing is open year round for recreational and most First Nation fishers. Some areas are closed seasonally to commercial fishing to protect moulting crabs and/or to provide fishing opportunities to recreational and First Nations fishers. All major fishing areas are considered fully exploited (DFO 2000). Research activities focus on collecting biological information, monitoring the effects of intensive fishing on yield and recruitment, and soft-shell monitoring in Crab Management Area A (Figure 1).

First Nations harvest of Dungeness crab for FSC purposes occur under FSC communal licenses and Aboriginal Fishing Strategy (AFS) agreements and include reporting requirements although data are not always reported or are often inaccurate (J. Nener *pers com*).

Recreational fishing regulations require individuals to obtain a BC Tidal Waters Sport Fishing License for fishing Dungeness crabs. Recreational fishers are allowed a daily limit of 6 and possession limit of 12 on the North Coast and West Coast of Vancouver Island, and a daily limit of 4 and a possession limit of 8 on the South Coast. Recreational fishers are not required to record or report catch of Dungeness crabs.

Current catch reporting for the commercial crab fisheries include completion of Crab Harvest Logs and completion of fish slips. Industry also participates in monitoring programs consisting of trap tags, fishing hails, on ground monitoring and collection of biological data. The objectives of the catch reporting and monitoring program are to ensure compliance with trap limits, obtain greater understanding of Dungeness crab biology in each management area, improve data quality on fishing effort and distribution, compliance with gear restrictions and ensure compliance with conservation measures (size and sex). In Crab Management Area A (Figure 1), vessels participate in a full monitoring program either through electronic monitoring (GPS and video data collection) or 100% on-board observer coverage. In Crab Management Areas B, E, G, H, I & J, random on-board observer coverage is required to monitor trap limits, fishing locations, soak times, gear restriction compliance, and compliance with conservation measures.

Prawns

Current assessment and management frameworks in B.C. do not rely on estimates of abundance for prawns. Recruitment overfishing in the commercial prawn fishery is managed using a fixed escapement strategy (Boutillier and Bond 1999a, 1999b). Decisions for closing the commercial fishery occur when the number of female catch per trap reaches a certain mean monthly index commonly referred to as spawner index (SI). A series of monthly indices was determined by Boutillier (1987) to allow an area to have an average of one female spawner per trap in March, taking into account natural mortality (Figure 3). During the fishing season, industry-funded at-sea observers sample commercial catches at the time of hauling to estimate female spawner abundance indices and sex and cohort composition on a per trap basis. When the mean spawner index from samples reaches 110% of the target spawner index for the month, the fishery is closed.

Management measures to prevent growth overfishing include a minimum size limit (33 mm carapace length [CL]) and seasonal closure of the commercial fishery until May to protect male spawners; this delay of the fishery also protects berried females and allows them to release their eggs before they are impacted by the fishery. First Nations and recreational fishers fish year round in most areas of the coast except in some high-use recreational areas where winter closures for recreational harvest are invoked if SI in the area is exceeded. Commercial effort is controlled through trap limits, daylight fishing restrictions and daily single haul provisions. Gear restrictions include maximum trap size, minimum mesh size and entry tunnel size. Each license is allowed 300 traps, which must be set in strings of no more than 50 traps. Vessels can stack two licenses, but the trap limit is dropped to 250 per license rather than 300 for single vessel licenses. Each string can only be hauled once in a 24 hour period, and gear must be tended between 0700h and 1900h (DFO 2004).

Continued study (since 1985) of prawns in Howe Sound, B.C. is the focus of assessment activities. Bi-annual surveys (fall and winter) take place in Howe Sound to evaluate the fixed escapement strategy, recruitment and productivity parameters. Additional research on trap efficiencies and bait effects are included in the research program.

First Nations' harvest of prawns for FSC purposes occur under FSC communal licenses and Aboriginal Fishing Strategy (AFS) agreements. The agreements include reporting requirements although data are not always reported or are often inaccurate (J. Nener *pers com*).

Recreational fishers are required to obtain a BC Tidal Waters Sport Fishing License. Fishers are allowed a daily limit of 200 prawns and possession limit of 400. There are no requirements to record or report prawn catches.

Current catch reporting for the commercial prawn by trap fishery include completion and submission of Harvest Logs and fish slips to DFO. Monitoring for the commercial industry involves a hail system prior to fishing and when terminating fishing. On-board observers collect spawner-index data and document rockfish encounters.

Nisga'a Final Agreement

The Nisga'a Final Agreement (finalized in May 2000) provides entitlement to Nisga'a citizens to harvest salmon and non-salmon species subject to conservation measures or public health or safety concerns. The Nisga'a Final Agreement provides fish allocations for salmon as a percentage of the total allowable catch (TAC) and makes provisions for overages and underages. For non-salmon species and aquatic plants, basic Nisga'a fish entitlements will be determined through a joint negotiation that considers: 1) current and past Nisga'a use for domestic (FSC) purposes; 2) the impact of conservation requirements and harvesting by others use for domestic purposes; 3) the biological status of the species; 4) changes in Nisga'a fishing effort; and 5) other relevant factors agreed upon by the Parties. Allocations for non-salmon species have yet to be determined although efforts have been made to resolve Nisga'a entitlements for Dungeness crabs (Alexander *et al.* 2003). One of the objectives of the Alexander *et al*. (2003) study was to "evaluate the effectiveness of the current management strategies (i.e. short seasonal commercial fishery late in the year combined with areas that are permanently closed) in ensuring sufficient availability of crabs for First Nation and recreational fishers".

The Nisga'a Lisims Government has conducted non-salmon catch monitoring programs to obtain accurate information of the catch of non-salmon species and relative effort for the Nisga'a non-salmon fisheries (Baxter and Azak 2003). The program is designed to assist in defining non-salmon entitlements for Nisga'a citizens as part of the Nisga'a Final Agreement. The catch monitoring program involved creel surveys or phone interviews of Nisga'a citizens (approximately 78% were interviewed in 2002) to determine whether fishers or their families harvested non-salmon species (Baxter and Azak 2003). Catch and effort was determined by collecting information on target species, location fished, gear type, dates, fishing times and total harvest by species (numbers or weights). For Dungeness crabs, bait type, number of traps, soak times and total catch of males, females and gravid females was obtained. For shrimp, gear type and total catch in pounds was collected.

Washington State Treaty Agreements

Prawns

The State of Washington and Tribal organizations enter into area-specific collaborative management plans (WDFW 2004a-f) with the following objectives:

- To preserve, protect and perpetuate Puget Sound pandalid shrimp resources;
- To provide for their sustainable harvest and equal sharing (50:50 split between Tribal and State fisheries) of the estimated harvestable surplus;

- To protect the habitat necessary to sustain these harvests; and
- To minimize bycatch mortality of other species.

Because of limited biological information available for Puget Sound pandalid shrimp, both parties share the goal of "using appropriate pre- and post-fishery sampling methodology, and appropriate sampling of commercial fisheries to provide a database for on-going shrimp population modeling, as well as collecting and analyzing additional information to improve shrimp fishery management". All the affected parties have an opportunity to participate in and review the designs of proposed studies to achieve these goals.

Harvestable surplus for pandalid shrimp stocks in areas with extensive historic fishery data are set based on historic harvests adjusted by recent fishery performance. Harvestable surplus for areas without extensive fishing histories are projected using amounts of appropriate shrimp habitat relative to historic fishing areas, again adjusted using recent fishery performance.

Puget Sound is divided into seven Crustacean Management Areas (Figure 4). The commercial fishery is managed using a season of mid-April to mid-September (Regions 1, 2W, 3 and 4) or to mid-October (Region 6), although areas may open earlier if test fishing indicates that less than 3% of spot shrimp with a carapace length (CL) of 34 mm or greater are ovigerous (Table 3). Seasons may be extended by two weeks if test fishing shows that the same limits for ovigerous females are met at the closing date (Regions 4 and 6, WDFW 2004d). A similar provision allows Region 3 to remain open after September 15, but requires weekly sampling and closure if ovigery exceeds 3% (WDFW 2004c).

Treaty ceremonial and subsistence (CS) and State recreational fisheries operate over a season of mid-April to mid-September (Regions 2W and 4) or mid-October (Regions 1, 3 and 6). Seasons are closed early for any party that has achieved their harvest share[2].

The fishery is further regulated using a minimum size of 30 mm CL. Gear must be marked with buoys, color-coded to identify State, Treaty and recreational gear (*e.g.*, yellow buoys are reserved for State recreational gear and this gear must be marked by yellow buoys only). Setting and pulling of pots is only allowed from one hour before sunrise until one hour after sunset. All pots must be equipped with biodegradable escape mechanisms (either rot cords on tie downs/hooks or panels).

Both State and Tribes are working to require a minimum mesh size of ½ inch (12.7 mm) for shrimp pots used in Region 4 (Central Puget Sound) (WDFW 2004d). They are also undertaking an education program to outline the benefits of using 7/8 inch (22.2 mm) mesh to reduce retention of sublegal prawns. This proposal may be appropriate for Region 4, which does not appear to support harvestable amounts of non-spot shrimp. However, Region 2W does support a considerable non-spot shrimp fishery, and there is resistance to a minimum mesh size that would eliminate the opportunity for this fishery

[2] Treaty and State commercial pot fisheries for shrimp species other than prawns ("non-spot shrimp") generally open April 16 (Regions 4 and 6) or May 1 (Regions 1, 2W and 3) and close September 15 (Regions 4 and 6) or October 15 (Regions 1, 2W and 3) or when respective harvest shares are achieved, which ever occurs first. Treaty and State shrimp trawl fisheries open April 16 (Region 3) or May 16 (Region 1) and close October 15 or when respective harvest shares are achieved, which ever occurs first. Region 3 carries out weekly sampling, and if count/lb exceeds 160 or ovigery exceeds 2%, the parties meet to develop a more extensive sampling program for the remainder of the season. Trawlers cannot target prawns, and any prawns caught incidentally are released and noted in the daily trawl log.

(WDFW 2004b). They are assessing the extent of smaller mesh size use in the recreational fishery and considering other means to protect prawns, including closure of the non-spot fishery when the prawn quota is taken and an appropriate minimum mesh size to protect small prawns. Non-spot shrimp pot fisheries are currently limited to depths less than 175 feet when the prawn fishery is closed in Region 2W.

Test fishing is undertaken prior to the season opening and after the season closes to assess prawn resources. There are also provisions in the plans to consider test fishing proposals in-season in support of quota adjustments, or exploratory fishing to identify new fishing areas.

Each party is responsible for compiling catch data by their group by area and gear type, and data are exchanged on the first and fifteenth days of each month that the fishery is open. If any share exceeds 80% of their planned harvest share, then data is exchanged weekly. Overharvest of shares by more than 2-3% in any area/gear combination results in the overharvest amount being subtracted from the planned share for that area in the following year.

Commercial landings are recorded on receiving tickets as whole weight, or designated as tails and the reported tail weight multiplied by 2.22 to standardize to whole weight. These tickets are to be submitted to the appropriate management authority within six days of landing. Fishers also submit harvest logs on a monthly basis. Receiving ticket numbers are recorded on harvest logbooks, and a sample of these are cross-checked each week, primarily to direct enforcement effort

Both State and Tribes collect information on recreational, ceremonial and subsistence harvests, and “strive to improve the scope and precision of non-commercial catch estimates”.

A post-season report, which includes harvest by fishery and area, test fishery data and results, resource assessment and other pertinent management information, is produced prior to December 1 of the year of the fishery, and a review of issues and suggested changes for the following year’s management plan are made.

A State/Tribal Shrimp Technical Group is developing processes and methodology to make quota adjustments based on fishery-independent data. Until such means are available, the following data are jointly reviewed to assess proposed quota adjustments:

- Total catch from at least the most recent three years of the fishery;
- Annual test fishery CPUE (catch per pot) prior to opening and after the fishery is complete;
- Annual CPUE (lbs/pot-day or lbs/pot-pulls) for at least the most recent three years;
- Annual total fishery effort for at least the most recent three years;
- Number of days fished in each season for each fishery for at least the most recent three years;
- Approximate size (acres or square feet) of the current quota area; and
- Distribution of fishing effort for the three most recent years.

These are the minimum data to be compiled and presented by the party proposing a quota adjustment; an adjustment occurs if there is agreement between both parties that the current quota is too high (quota decrease) or too low (quota increase).[3]

Dungeness Crabs

Area-specific[4] crab management plans (WDFW 2004g-m) have the following objectives:

- To preserve, protect and perpetuate the Dungeness crab resource;
- To design fisheries to provide State and Tribes equal sharing of the agreed crab harvests in each area;
- To provide a coordinated system for accurate catch counting and timely reporting of catch to all affected parties;
- To provide effective enforcement of State and Tribal regulations by the respective parties;
- To maintain consistent conservation-based regulations regarding fishing seasons, legal size and sex of harvestable crab, and legal gear used in State and Tribal fisheries;
- To identify and minimize, as practical, bycatch mortalities of crab from other fisheries;
- To minimize fishery-induced mortality of soft-shell crab by closing during the peak moulting period; and
- To minimize conflicts between all crab fisheries, and between crab fisheries and other fisheries.

The harvest is limited to only male crabs greater than 6.25 inches (159 mm) carapace width (CW), measured notch-to-notch. Retention of female or soft-shell crabs is prohibited; they must be returned to the water alive. Only traps, ring nets or hand-operated instruments that do not penetrate the shell can be used; all parties use commercial gear as the fisheries are competitive in nature. All crab traps must have two escape ports not less than 4.25 inches (108 mm) inside diameter, and either a three by five inch (76 by 127 mm) rot panel or rot cord attached to the trap lid hook. Individual traps or groundlines must be marked by buoys; commercial traps can be marked with any color or combination of colors except half red and half white. Gear cannot be tended more than one half-hour before sunrise or one half-hour after sunset.

All fisheries except ceremonial fisheries held for significant cultural events close during the peak moulting period to prevent soft-shell crab handling mortality (Table 4). Test fishing to determine if hardness criteria are met is undertaken pre-season (in some cases) or can be conducted in-season for hardness or other biological information. Both parties may participate in or observe test fishing, and the results are discussed jointly to agree on required management actions.

A variety of area closures are used for a number of purposes, including preserves (no harvest allowed), exclusive Tribal management zones (no State fisheries allowed), non-

[3] Although there are disparities in data quality between State and Tribe, the system appears to work well, in the opinion of one Washington State fishery manager.

[4] Puget Sound is divided into seven management areas. These are not licence areas; anyone possessing a Puget Sound commercial crab licence can fish any of the management areas. In British Columbia, commercial fishers elect to fish a given management area and are restricted to that area.

commercial zones (no commercial fishing year-round) and limited commercial zones (open to commercial harvests for a portion of the year, or if recreational fishers have taken their allocations) (Table 5).

The initial harvest quota is set as the average of a number of previous years' total catch (seven years in Region 1, three years in Regions 2E and 5, not specified for 2W, 3, 4 and 6)[5]. There are provisions in the plans to review fishery information on a regular basis during the season to determine whether more accurate estimates of total catch at season's end can be made, through comparison of catches to date relative to the fishery in the previous five years. In Region 1, CPUE from the first two to three weeks of the State commercial fishery are compared to previous years, and an algorithm used to relate changes in CPUE to changes in estimated quota for the year.

The fishery in each area closes upon achievement of a party's harvest share or on the specified closing date. In some cases fishing ceases in areas as abundance is reduced below point of economic feasibility, and fishers relocate to other open areas where returns are higher.

Data quality varies considerably between parties. Although fish tickets are required, they cannot be entered in a timely enough fashion to be used in-season. The primary in-season data source is reports (hails) from buyers. Buyer hails are audited against fish ticket data when the latter become available post-season. Some Tribes have soft data systems and provide updates to the State, but the utility of these updates varies considerably. Reporting of subsistence catches by the Tribes does not work particularly well, but these are generally a small component of the Tribal fishery.

Quotas and fishery performance are reviewed annually prior to setting initial quotas for the following year. In some instances, initial quotas are reduced when poor performance of the fishery in the previous year (*e.g.*, neither party approaching expected harvest shares) indicates that initial quotas were misleadingly high.

Biological Considerations

Dungeness Crabs

Dungeness crabs are reported from Tanaga Island in the Aleutian Islands to Magdalena Bay, Mexico, from the intertidal to depths of 179 m (Hart 1982). Their preferred habitat is sandy bottoms and eelgrass beds less than 50 m deep and subject to moderate to strong currents (DFO 1999, 2000).

As with all crustaceans, crab growth is not continuous, but spasmodic (Hart 1982). Crabs grow by producing a new shell and shedding the old shell through a process called moulting. The old shell splits along the seam between the carapace and abdomen, and the crab "backs out" of its old shell. The crab quickly expands the new shell through uptake of water. During the post-moult period the new shell is soft making the crab

[5] Differences in the number of years used to calculate average catch are a function of fishery history. Region 1 has been the historic base of the Dungeness crab fishery in Puget Sound, and as such the fishery has changed little for a long series of catches. Other areas have experienced increased effort and catches recently, which may mean that historic catches from an undeveloped fishery do not reflect the productive capacity of these areas (D. Velasquez, WDFW, *pers com*.).

vulnerable to predation and sensitive to handling injuries until it hardens (after about 2 months). The crab cannot defend itself with soft claws and cannot move about at normal speed. Frequency of moulting depends on temperature, size, sex and sexual maturity. Immature crabs may moult several times a year while mature crabs may moult once a year or every two years. Butler (1961) reported moult increments of 20-29% for male crab between 80-154 mm CW, decreasing slightly thereafter. Females, however, only exhibited moult increments above 20% to 99 mm CW, with increments steadily decreasing thereafter.

Sexes are separate in Dungeness crabs and sexual maturity is achieved after about 2-3 years, corresponding to 10-11 moults. Males mature at approximately 116 mm CW and females at 100 mm CW (Weymouth and MacKay 1936, MacKay 1942, Butler 1960). Fertilization is internal, and mating occurs immediately after the female moults. Male crabs "embrace" hard-shell females until they moult, then mate with them (MacKay 1942, Butler 1960). Spermatozoa remain viable in the oviduct until the female's ova mature, fertilization occurs in the oviduct, and the eggs are extruded and carried in a mass attached to the pleopods on the underside of the female's abdomen. Females carrying eggs are termed "berried". Females may produce three to four broods in their lifetime, totaling approximately three to five million eggs (MacKay 1942).

Mating occurs in B.C. from April to September, with peaks of mating activity varying from area to area (MacKay 1942). Hatching occurs from December until June, with a peak in March. Larvae progress through a sequence of stages including protozoeae, several zoeal stages, megalops and finally settle to a benthic existence as post-larval crabs. Megalops larvae are found primarily in July and August in B.C.

Maximum size for males in B.C. is 220 mm CW (DFO 2000), and maximum age is likely eight years (Butler 1961). Males will generally achieve legal size in about 4 years (Butler 1961, 1986). Female Dungeness crabs rarely grow to legal size because as they mature, most of their energy is devoted to egg-production.

Prawns

Prawn populations in B.C. are near the center of the eastern Pacific distribution. *P. platyceros* is reported from Unalaska Island to San Diego in the eastern Pacific and from Vladivostok, Hokkaido, the Japan Sea and Korea Strait in the western Pacific, from the intertidal to depths of 487 m (Butler 1980). Normal adult habitat is rocky areas between 70 and 90 m in depth.

Prawns are short-lived animals with a maximum life span of four years (Butler 1980). Prawns are one of many pandalid shrimp that are protandadrous hermaphrodites, beginning their post-larval life as males and then changing into mature females in their final years of life (Butler 1980). Spawning occurs in the fall (usually complete by October) and females carry eggs until they hatch in March and April. Larvae are initially found in adult habitat, but by mid-summer most late larvae and post-larval prawns are found shallower (≤ 54 m), although some settle at adult depths. Prawns mature as males in their second autumn, and function as males for another year. Some males begin transition to females after two years of life and virtually all are female by their third birthday. Once a female is carrying eggs on her abdomen, she will no longer moult and grow. During this phase of life the overall biomass of females declines due to losses from natural mortality and fisheries (Boutillier and Bond 1999a). Age 3+ females spawn in the fall and disappear

from normal adult habitat the following spring after egg hatch, and are believed to die. Maximum size for male prawns in British Columbia is 48.1 mm CL and 230 mm total length (TL), and for females is 61.1 mm CL and 253 mm TL.

The commercial fishery mainly targets prawns in the final two years of their lives (age 2+ males and age 3+ females).

Data Sources

Landings information was obtained from either commercial logbook data stored at the Shellfish Data Unit at the Pacific Biological Station or commercial fish slip data from DFO Pacific Region's Catch Statistic Unit. Fishery independent data came from DFO research surveys. Other data were obtained from technical and manuscript reports.

Historical Landings

Under treaties, allocations can be delivered in several ways such as: First Nation access areas; per capita allocation; harvest rate; or fixed quotas. With fixed quotas, allocations can be derived in two ways: 1) a percentage of the total allowable catch (TAC) based on an absolute abundance estimate; or 2) a percentage based on the average historical production from an area over a specific period of time.

For many of British Columbia's commercially exploited marine invertebrate species, commercial allocations or TACs are based on abundance estimates as the product of density per unit habitat times the habitat area. This is usually obtained from fishery independent surveys. As previously mentioned, Dungeness crabs and prawns are not managed on abundance estimates. In order to develop and implement allocations, either abundance-based or through fixed quotas, new management and assessment frameworks would need to be developed in order to obtain abundance estimates for crabs and prawns.

Alternatively, allocations may be based on average historical production derived from commercial logbook or commercial fish slip data. Some advantages in using historical catch data are:

- It is relatively inexpensive in that it doesn't require any surveys;
- The information may be readily available and easily computed; and
- It is easily understood and easy to implement (Table 6).

On the negative side, catch is a poor means to tracking abundance. Catches rarely exhibit a steady state due to natural population fluctuations, especially with short-lived animals which exhibit highly variable recruitment patterns. Catches are also influenced by changes in management strategies or economic conditions. They don't provide information on stock size and present a risk to over-harvest of stocks of low abundance and under-harvest of stocks of high abundance (Rutherford *et al.* 2004a). Catch information is usually only available from commercial fishing sources while recreational and First Nations catch data are generally non-existent for non-salmon species. Even though recreational fishers must obtain a British Columbia Tidal Waters Sport Fishing License to fish Dungeness crabs and prawns they are not required to record or report catch of invertebrate species. Creel surveys are meant to capture recreational catch and effort information; however they are usually designed to monitor recreational salmon

catch. First Nations are required to report catches, however data are not always reported and the accuracy of data reported are often questionable.

One problem in interpreting historical catch data is understanding the completeness of the data set (Hilborn and Walters 1992). Rarely are all sources of fishing mortality included and at best, catch is only available from commercial fishing data sources. Fish slip data don't accurately represent catch because fishers often don't report private sales, personal consumption or product loss. They also don't differentiate catch and areas fished even though fishers often move between areas.

Logbooks are better but caution is advised when interpreting the data because they require accurate reporting and understanding by fishers (Hilborn and Walters 1992). Data collected under voluntary logbook programs can lead to questions of how representative the data are due to the variability in the number of vessels participating in the program (Rutherford *et al*. 2004a). Mandatory logbook programs, in general, can provide good information on area fished, catch in terms of weights or numbers and effort information but problems occur when information is not filled in correctly or when information is completely missing. However, catch data becomes more reliable when at-sea observers or dockside validators are used to sample catch and validate landings. The development of GPS (Global Positioning System) technology and electronic navigation equipment through the 1990's has provided greater accuracy to reported fishing locations.

Decisions of which time period to use will play an important part in calculating average historical production and setting domestic fishing allocations. One must consider the data source (fish slips vs. logbooks or combination of both), reliability of data (volunteer vs. mandatory reporting), determine if any significant management changes were made during the time period or if market conditions have changed significantly. In some areas, particularly remote locations, commercial landings information may not be available because commercial activity maybe non-existent.

Historical Commercial Catch Data for Dungeness Crabs

Annual harvests naturally fluctuate substantially over time because of environmentally induced variable crab settlement and survival (Butler 1984). A common assumption is that pre-season abundance of legal size male Dungeness crabs is a reflection of landings for that year (Methot and Botsford 1982) although many crab fisheries in B.C. are open all year. This would probably be true if all sources of fishing mortality are counted. Catch information for Dungeness crabs in B.C. includes only commercial fishing landings. Recreational and First Nation catch of Dungeness crabs are unknown. Lack of catch reporting, fraudulent catch reporting and inaccurate reporting have been and remain a significant problem in the commercial crab industry (Winther and Phillips 2000; DFO 2005). Crab logbook data are fraught with many problems such as erroneous fishing locations; positional data often don't match fishing activity; and missing catch information. Fish slip data are not any better because of problems with reporting. Public or dockside sales can make up a significant portion of sales but are not often reported on fish slips. There is also a difference in reported landings when comparing commercial logbook and fish slip data (Figure 5). However, improvements in catch reporting are being made through implementation of on-board monitoring and electronic monitoring programs.

Until there are significant improvements to commercial catch reporting and other sources of fishing mortality (recreational and First Nations catch) are included in landings, it would

be unwise to set allocations for crabs based on commercial logbooks and/or fish slips. As overall catch reporting improves, landings could serve as a proxy for legal-size male crab abundance.

Historical Commercial Catch Data for Prawns

Historical catch data for prawns are only available from commercial fisheries. Recreational catch is unknown but is probably considerable in some high use recreational areas (*e.g.*, Howe Sound, Saanich Inlet, Stuart Channel, Alberni Inlet). First Nations FSC catch of prawns is unknown.

Commercial logbooks provide more reliable catch information than commercial fish slip data for historical production of prawns. Morrison *et al.* (2002) highlighted problems with commercial prawn fish slip data with respect to how catch and area were reported and keypunched. With the commercial logbook program, prawn fishers record the position and catch (in weights) from each string of gear. A number of significant changes to management of commercial prawn fisheries in B.C. have occurred since 1979 that may affect the utility of commercial catch data as an index of abundance (Table 7).

Indices of Abundance

CPUE as an Index of Abundance

Given that proportional changes in fishing mortality (removals of a target animal) are equal to proportional changes in the total population of the targets, catch-per-unit effort (CPUE) could be used as an index of abundance.

An important factor when considering CPUE as an index of abundance is understanding the relationship between CPUE and abundance (Hilborn and Walters 1992). They discuss three possible relationships between CPUE and abundance: 1) **hyperstability** is when CPUE remains relatively constant throughout a fishery before a significant decline in CPUE is detected. It usually occurs in smaller spatial scales where fishers will seek out areas of highest fish densities to maintain an expected level of catch; 2) CPUE is **proportional** to abundance when catch declines as abundance declines; and 3) when CPUE declines at a much faster rate than abundance and appearing as though the stock has been depleted. This is known as **hyperdepletion**.

Problems such as hyperstability, unstandardized fishing effort, changes in catchability and gear saturation are well known when using CPUE as an index of abundance. If fishery dependent CPUE is to be used to monitor fishery performance then it is necessary to standardize effort. Some of this work may include standardizing traps; keeping soak times short and consistent (or weighting soak times); and catch reporting to include both weights and numbers (since population is generally represented by numbers of individuals whereas catch is often reported only as a combined weight).

Fishery Dependent CPUE as an Index of Abundance for Dungeness Crabs

Harvest Rate Approach

Smith and Jamieson (1989a) stated that as long as samples are equal and soak times are short and consistent (1 to 2 days), mean catch per trap could be used as a reliable index of abundance. However when soak times are longer, they recommend standardizing effort because of: 1) agonistic interactions of crabs; 2) changes in bait effectiveness; and 3) crabs escaping from traps.

Due to the competitive nature of the commercial crab industry, fishers will tend to soak their gear for short periods of times (usually 24 hrs) early in an opening to maximize their catch and then gradually increase soaks as stocks get depleted. A pattern of rapid reduction in CPUE is usually seen in areas of intensive fishing such as the Fraser/Delta commercial fishery[6] (Figure 6).

Allocations could be met by setting a fixed harvest rate to an index of abundance (mean commercial CPUE of legal-size male crabs). Managers could decide to close an area to commercial fishing when a decline in commercial CPUE of legal-size male crabs at the beginning reaches a target level (the ratio of CPUE at the beginning and during the fishing season would reflect the harvest rate). In areas of intensive fishing, fishing mortality would be much greater in comparison to natural mortality. In areas with lower fishing mortality, it could be assumed that natural mortality would be offset by undersized crabs moulting to legal size (i.e. non-moulting period).

Timing of the opening and closure of crab fishing areas will be critical to meeting First Nations allocation requirements. Even though a portion of legal-size male crabs would be available after the commercial fishery has closed it will be more difficult to capture legal-size male crabs. The approach of this program is based on declining commercial CPUE, meaning there would be progressively fewer legal crabs available for harvest through out the season. In other words, it's easier to capture legal-size males when abundance is high and harder when abundance is low. Therefore, managers may choose to delay opening an area to commercial fishing to allow First Nations access. It's important to note that most First Nations want year-round access as well as the ability to fish with traditional methods such as hand-picking, which requires higher levels of abundance than will remain after a commercial fishery.

Once an area closes to commercial fishing because the target level in commercial CPUE is reached, it's unlikely that the area would re-open to commercial fishing until the following season. This would probably mean a short commercial fishing season when abundance is low and longer season when abundance is high. A decision to re-open an area to commercial fishing would have to be based on an increase in abundance of legal crabs determined by fishery independent methods (if there are multiple moults through out the year).

This management system has not been used in other fisheries and would need to be tested by area due to local differences in stock structure, recruitment rates and biological

[6] The Fraser/Delta commercial fishery, Crab Management Area I (Figure 1) is open from late June to November 30. A seasonal closure from December 1 to late June of the following year is in place to protect soft-shell and female crabs from unnecessary handling mortality.

productivity. It's important to recognize that the commercial CPUE from one area could not be used in adjacent areas (*e.g.*, statistical sub-areas) because of the spatial differences in Dungeness crab populations.

Data requirements for this approach would include:

- Commercial catch sampling at-sea at the beginning of the fishery or test fishing immediately prior to opening to measure initial CPUE by sex and size category; and
- Continual in-season on-grounds sampling of catch to monitor decline in CPUE levels.

Commercial logbooks alone would not be enough considering the reporting errors associated with them and the incentive for fishers to misreport catches if it were perceived to limit fishing opportunity.

Each First Nations area would require its own assessment and catch monitoring program. Assessment programs are necessary for receiving, analyzing and reporting data. They will also be necessary in carrying out experiments aimed at standardizing commercial effort. Onboard sampling programs need to be developed for collecting data and monitoring compliance with management regulations and requirements. Open exchange of information and acceptance of common program objectives between First Nations fisheries staff and DFO will be critical to the success of the program.

The critical assumptions for commercial CPUE of legal-size male crabs as a proxy of abundance are:

- Fishing adequately covers the area;
- There are no external sources of crabs or immigration and emigration are equal;
- Fishing takes place during non-moulting periods;
- Natural mortality of legal-size male crabs is offset by undersize male crabs moulting to legal-size (natural mortality between moults is relatively low and in all cases where a commercial fishery exists would be exceeded by fishing mortality); and
- All crabs above legal-size have the same probability of capture.

Because catch rates are influenced by trap size, soak times and bait types, implementation of standardized gear (trap type and bait) and soak times are necessary, or experiments to standardize effort can be carried out (Smith and Jamieson 1989a). Patterns of hyperstability of CPUE are probably unlikely because large Dungeness crabs are more or less evenly distributed over their habitat rather than concentrated in high densities. Also, commercial fishers tend to spread their gear over entire habitats rather than concentrating gear in one area (A. Phillips *pers com*).

One potential problem is in areas of lower commercial fishing effort and an undetermined moulting period; CPUE may be sustained by crabs moulting to legal size during the fishery. Also any harvest by First Nations or recreational fishers before and during commercial fishing may alter the level of harvest. In some areas, First Nations and recreational fishers are permitted to fish for Dungeness crabs during commercial fishing closures (*e.g.*, soft-shell periods).

A benefit of this program is that it is responsive to annual fluctuations and results in greater catch in years of high abundance (as indexed through the CPUE) and lower in years of low abundance. In other words, stocks are protected in low abundance years and catch is maximized in high abundance years.

Fishery Independent CPUE as an Index of Abundance for Dungeness Crabs

Harvest Rate Approach

Fishery independent surveys could be used to establish pre-fishery abundance indices of legal-size male crabs. In-season commercial CPUE of legal-size crabs would be weighted against pre-fishery abundance indices and when a decline in commercial CPUE reaches a target level, the commercial fishery is closed. Alternatively, in-season fishery independent surveys could be used to monitor exploitation levels. The ratio of fishery independent CPUE from the beginning and during the fishery would reflect the level of exploitation.

For this approach, a First Nations area would be closed to commercial and/or recreational harvest until the First Nations has achieved their share. Decisions to open the area to commercial and/or recreational fishing could be made when a decline in fishery independent CPUE reaches a target exploitation level. For example, if the pre-fishery CPUE is 5 legal-size male crabs/trap and the target exploitation level is 80%, when CPUE declines to 4 crabs/trap the area would open for all sectors until such time moulting takes place. This approach would likely work best in areas of intensive commercial fishing where a defined moulting period is known to exist. Seasonal closures to all fishing would allow male stocks to rebuild and minimize the impact of losing crabs to handling mortality. Natural mortality rates increase significantly during moulting and soft-shell periods because crabs are more susceptible to predation and injury as well as the moulting process itself (Zhang *et al*. 2002, 2004). It is important to note that most First Nations requirements are ongoing, meaning year-round access with the ability to fish with traditional methods such as hand-picking.

With this management system, pre-fishery CPUE should be based on legal-size male crabs at highest abundance which usually occurs following a moult event. In areas where moult timing is unknown, sampling should take place to identify soft-shell periods. If there are multiple moults throughout the fishing season, it may be necessary to close a fishery when CPUE reaches a low level consistent with other fisheries and remain closed until the CPUE of legal crabs reaches a pre-determined level. The CPUE at which a fishery would re-open would have to be determined by area, through test fishing if necessary.

This approach has not been used in other fisheries and would need to be tested by area due to local differences in stock structure, recruitment rates and biological productivity.

The data requirements for this program are:

- Pre-fishery surveys to establish initial CPUE levels; and
- In-season catch sampling for sex and size by at-sea observers to monitor declines in CPUE levels.

Commercial CPUE will need to be weighted (correction factors) against fishery independent CPUE. Experiments would need to be carried out in order to compare catch

rates from various commercial trap types to a standard trap type. Alternatively if commercial CPUE is unreliable then continual in-season fishery independent surveys of index sites using standardized gear, soak times and bait would be necessary to measure CPUE and track exploitation levels. Either option will require vessel time and sampling material (traps, lines, bait, floats etc) to carry out fishery independent surveys. Onboard sampling programs would also need to be developed to collect data and monitor compliance with management regulations and requirements.

Critical assumptions with this program are:

- Sampling adequately covers the area;
- Populations are closed or immigration and emigration are equal;
- Sampling takes place during non-moulting periods;
- Natural mortality of legal-size male crabs is offset by undersize male crabs moulting to legal size (i.e. a non-moulting period); and
- All crabs above legal-size have the same probability of capture.

Although this type of program would be more expensive, pre-fishery abundance indices would enable managers to delay opening areas to commercial and/or recreational fishing until First Nations FSC requirements are achieved. In years of low crab abundance, a delay in opening to commercial and/or recreational fishers maybe warranted. As longer time-series of fishery independent data develops, it might be possible to predict pre-season abundance levels.

Again the benefits and disadvantages are the same as previously described. In areas with lower commercial fishing effort and an undetermined moulting period, CPUE may be sustained by crabs moulting to legal size during the fishery; any harvest by First Nations or recreational fishers before and during commercial fishing may alter the level of harvest. However a benefit to this approach is its responsiveness to annual fluctuations in abundance.

Fishery Dependent CPUE for Prawns

Harvest Rate Approach

Dunham *et al*. (2002) described the use of fishery dependent CPUE as an option for managing humpback shrimp fisheries. They suggest that if sampling adequately covers the area, then the CPUE index should reflect population trends. The CPUE index in this example is the number of females, or potential females (depending on the time of year), per trap. Based on fishery independent surveys they computed a mean CPUE index of 47 female shrimp per trap (age 3 shrimp in November) in Drury Inlet, B.C. (Table 8). Catch levels could then be based on a harvest rate applied to the mean number of female shrimp per trap as follows:

For a 25% HR, catch level = 0.25 x 47 = 12 females per trap, therefore CPUE should not fall below 35 females per trap.

For a 33% HR, catch level = 0.33 x 47 = 16 females per trap, therefore CPUE should not fall below 31 females per trap.

For a 40% HR, catch level = 0.40 x 47 = 19 females per trap, therefore CPUE should not fall below 28 females per trap.

The authors then modeled catch levels over time for humpback shrimp in Drury Inlet using natural mortality estimates from fishery independent surveys. From this, monthly CPUE cutoff levels were estimated for each of the harvest rates used in the example above (Figure 6). Although a 40% HR was considered they recommended harvest rates of 25% to 33% for humpback shrimp to prevent recruitment overfishing.

This method has not been specifically been applied to prawns but is one of the methods under consideration for a humpback shrimp trap fishery in Prince Rupert (D. Rutherford *pers com*).

Data requirements for this type of program would include:

- An estimate of natural mortality for the specific stock determined through fishery independent surveys;
- Catch sampling by sex and age at the beginning of the fishery to measure CPUE and establish shutoff points; and
- Continual in-season sampling of catch to monitor target shutoff points.

The critical assumption of this type of program is that CPUE is reflective of population abundance. For this assumption to be met extreme care must be taken to ensure sampling distribution adequately covers the area and that changes in fishing effort are accounted for. Because the efficiency of trap gear has been shown to change, implementation of standardized gear (trap type, bait, etc) and soak time is necessary, or alternatively an ongoing assessment program to standardize effort can be carried out (Rutherford *et al.* 2004b).

Some of the benefits of this approach are that harvest is based on a biological threshold to ensure conservation and sustainability of the specific stock being fished. This approach is also somewhat responsive to annual fluctuations in abundance and results in greater catch in years of high abundance (as indexed through the CPUE) and conversely lower catch in years of low abundance. A disadvantage to this approach is that no measure of total abundance can be derived; therefore a TAC (in absolute numbers or weight) cannot be set.

Fixed Escapement Approach

Similarly, the fixed escapement spawner index program for prawns could be used to portion catch (Boutillier and Bond 2000). In-season spawner index sampling is essentially measuring the abundance of age 2+ and age 3+ animals. Therefore spawner index could be used as a tool for portioning catch to user groups by setting differential mean monthly indexes above the target spawner index. For this method to work there needs to be sequential timing differences in prosecution of fisheries between user groups or large differences in harvest efficiency of a user group that results in a shortening of their season relative to the other user groups. It's important to note that raising the mean monthly index for non-First Nation harvesters may not guarantee year round access for First Nation harvest. Variation in natural mortality precludes any guarantee of year round access although Boutillier and Bond (2000) pointed out that the current fishery may not be at MSY

so setting a more conservative mean monthly index may result in greater surplus of recruits.

Differential SI levels have been implemented by resource managers to portion catch between the commercial and recreational sector in selected areas along the coast of British Columbia (DFO 2004). Areas of high recreational use have a SI cut off for the commercial fleet set at 25% above baseline. When the +25% threshold is reached in an area then the area is closed to commercial harvest but remains open for the recreational sector. If the index falls below the base index then the area is closed to all discretionary harvest. The rationale behind this strategy is to ensure recreational fishing opportunities. An example of the cutoff points used in-season is presented in Table 9.

Fishery independent surveys would be required to obtain area-specific natural mortality rates to better estimate a site-specific mean monthly index. Each area being considered would also need its own assessment and spawner index sampling program. Sampling for SI needs to be designed to ensure they are reflective of the prawn population in the specific area. This would require a coordinated effort of First Nation fisheries staff, commercial catch monitoring staff, and DFO staff to ensure adequate onboard sampling and timely analysis of data.

The assumptions for this program are very similar to those identified previously for the fixed harvest rate approach. Extreme care must be taken to ensure sampling distribution adequately covers the area and that changes in fishing effort are accounted for.

Again one of the benefits of this approach is that harvest is based on a biological threshold to ensure conservation and sustainability of the specific stock being fished. It would also fit well with the current management system for prawn by trap fisheries. This approach is also responsive to annual fluctuation and results in greater catch in years of high abundance and conversely lower catch in years of low abundance. Disadvantages to this approach are that no measure of total abundance can be derived; therefore a TAC (in absolute numbers or weight) cannot be set, and that regular reviews of recent SI data are necessary for timely management of the fishery.

Other Abundance Estimation Methods

Change-in-Ratio

This method takes advantage of the changes in sex or age class ratios from the selective removal of an animal over time (Udevitz and Pollock 1991). When the removal of an animal is directed toward a single size or age class, the proportional change in class can provide information about the exploitation rate and when combined with total removals, total abundance can be estimated. This method works best during short fishing seasons and when exploitation rates are high enough to cause changes in size proportions (Dawe *et al*. 1993).

Chen *et al*. (1998) and Dawe *et al*. (1993) estimated the exploitation rate and population size of legal-size male snow crabs (*Chionoecetes opilio*) in St. Mary's Bay, Newfoundland using the change-in-ratio method. Claytor and Allard (2003) used a modified change-in-ratio method for estimating in-season Atlantic lobster (*Homarus americanus*) exploitation rates, based on continuous sampling with fishing. In each example, legal and sublegal sizes were used as reference classes.

For Dungeness crabs, legal and sublegal size male crabs would be a natural division. A change-in-ratio program would involve fishery independent surveys immediately before and after a commercial fishery. Fixed sampling sites with standardized fishing gear are necessary to reduce biases associated with catchability of the two classes. An accurate catch monitoring program is necessary to track removal of individuals and to ensure quotas are not exceeded. Plant sampling for individual weights and lengths would be required to estimate catch proportions of each class (harvesting of undersized crabs does occur) and to obtain a mean individual weight if conversions to total numbers are necessary. In-season catch sampling would be required to gather information on moult timing for crabs, discard ratios and population structure.

For prawns, a natural division would be age 2+ and 3+ animals. The survey methodologies would be similar to Dungeness crabs with pre and post fishery surveys. In-season sampling would be required to estimate catch proportions of each age class. A highly accurate catch monitoring program is necessary to ensure target harvest rates or quotas are not exceeded.

The assumptions associated with change-in-ratio methods are:

- The population is closed or immigration/emigration rates are equal for both classes;
- Mortality rate and moulting are equal; and
- Animals have the same probability of capture in each survey.

An advantage with change-in-ratio methods is that it provides estimates of pre- and post-season abundance. Also, this method provides estimates of exploitation, catchability coefficient and possibly, pre-recruit abundance (Dawe *et al.* 1993). One pitfall is the cost associated with pre- and post-fishery independent surveys. This requires vessel time and sampling material (traps, lines, bait, floats etc) to carry out fishery independent surveys.

Index Removal Methods

Index removal methods are similar to change-in-ratio methods. It makes use of declines in relative abundance due to a known removal provided that declines in catch rate (CPUE) are proportional to abundance (Chen *et al.* 1998). Using Chen *et al's* (1998) example, if the catch rate of legal male crabs before the fishery is 10 legal male crabs per trap and is 7 legal male crabs per trap after the fishery with a total of 300 crabs removed, this results in a loss of (10-7)/10 = 3/10 or 30% of the population. Thus, the population prior to the fishery was 1,000 legal male crabs.

Estimates of legal-size male snow crab populations in St. Mary's Bay were determined by Chen *et al*. (1998) using index-removal methods.

Pre- and post-fishery research surveys with standardized fishing methods and locations are required to collect information on catch rates and catch composition. In-season sampling is needed to gather information on catch composition, while catch monitoring is necessary to track removals and monitor quotas.

The assumptions with index-removal methods are:

- The population is closed or, alternatively additions equal losses (excluding removal); and
- All animals have the same probability of capture by one unit of sampling effort during each survey.

The benefits with index-removal methods are similar to change-in-ratio methods. Pre- and post-fishery abundance, along with exploitation rates and catchability can be obtained with index-removal methods. Again costs would be a disadvantage because pre- and post-fishery independent are necessary.

Tagging Experiments

Tagging studies are useful for estimating abundance, movement, harvest rates, and growth. Effective tagging studies require a significant portion of the population to be tagged and an effective tag recovery effort (Hilborn and Walters 1992; Seber 1982).

There are four common assumptions with mark-recapture studies (Seber 1982):

- Animals are not affected by tagging or tags will not be lost;
- Marked animals completely mix with unmarked animals;
- Marked animals have the same probability of capture as unmarked animals; and
- All marks are reported when animals are recaptured.

Mark-recapture studies for Dungeness crabs and prawns have been developed. Alexander *et al*. (2003) and Smith and Jamieson (1989b) used mark-recapture techniques for estimating harvest rates for Dungeness crabs by the commercial fishery in the Nass Estuary and Tofino, B.C. respectively. Alexander *et al*. (2003) went further by estimating total population size of Dungeness crabs in the Nass Estuary. Kimker *et al.* (1996) used mark-recapture techniques to examine growth and longevity in spot shrimp (*Pandalus platyceros*).

As previously discussed, sufficient sampling is necessary to capture, mark and recapture animals. A tag reporting and/or catch monitoring program is necessary to obtain tag recovery information. A monetary reward program was implemented in the Alexander *et al*. (2003) study to encourage fishers to return information regarding tagged crabs. Alternatively, onboard catch sampling is another method at obtaining tagged animals. Biological information would need to be collected in order to assess crab or prawn populations with respect to all harvesting. This includes handling effects, growth rates, moult timing and future recruitment. Once abundance estimates have been determined, a catch monitoring program is required to ensure quotas are not exceeded.

A problem with mark-recapture programs is the difficulty in testing the number of assumptions. Problems with mark-recapture techniques for crustaceans, particularly for prawns include tag loss due to moulting, high tagging mortality and tagging inhibiting growth (Boutillier and Bond 1999a). Mark-recapture programs are generally expensive and time consuming since a significant amount of effort is required to capture, tag and release animals. However, the tagging study of Dungeness crab by Alexander *et al.* (2003) proved useful for estimating total abundance and exploitation rates of legal-size male crabs in the Nass Estuary.

Video Assessment

Aerial counts and photography are standard assessment techniques used for estimating abundance of terrestrial wildlife (Schwarz and Seber 1999). Estimating fish abundance or density is possible with the use of an under-water camera system and has been tested for rockfish (Martin and Yamanaka 2004). They were able to estimate area from the video footage through calibrations in the field of view of the camera. Lasers were deployed with the under-camera system to estimate size of animal.

Video assessment has not been tested for prawns although it may prove to be difficult due to the habitat and behaviour of prawns. Adult prawns occupy rocky habitats and are known to hide in spaces under rocks or in crevices (Butler 1980). It might also be difficult to tow an underwater camera over rocky habitats. If towed too close there is potential for damage to the camera or if towed too far, prawns may be difficult to see.

Dungeness crabs occupy sandy bottoms and eelgrass beds and often bury themselves for protection when frightened (DFO 1999, 2000; Butler 1984). A ROV (self-propelled remote operated vessel), equipped with an underwater camera, was deployed in 1995 in Indian Arm, Cowichan Bay and off the Fraser River to assess Dungeness crab habitat and behaviour (A. Phillips *pers com*). One of the problems with the ROV was that Dungeness crabs were difficult to see because clouds of sand and debris were kicked-up by the ROV. Of interesting note, the researchers were able to identify buried female Dungeness crab by the depression they made in the sand (A. Phillips *pers com*). There is the possibility that Dungeness crabs may have buried themselves because they were frightened by the ROV. An underwater camera towed behind a vessel would have to be designed so as not to frighten crabs. Lasers could be deployed to estimate size and since Dungeness crabs are sexually dimorphic, it might be possible to distinguish them by sex.

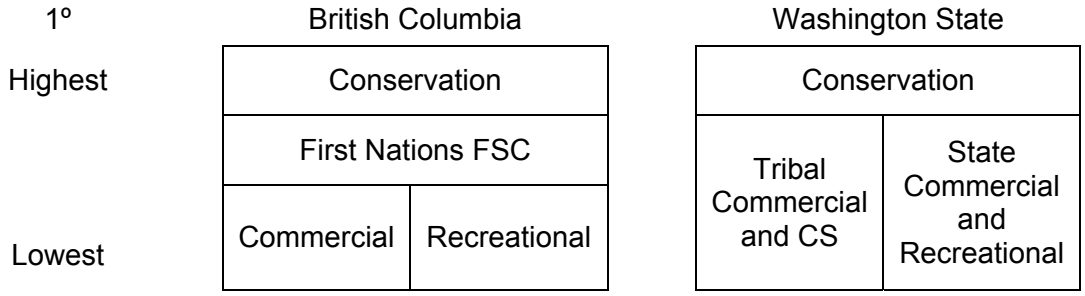
The costs for developing the underwater video assessment are likely to be high because it's a relatively new tool for fisheries stock assessment. Considerable time would have to be invested to test different underwater systems in order to see which works best in different habitat types. However, once the technique has been developed, the system could be deployed with relative ease. A small underwater camera could be easily transported and would be less disruptive than more tradition assessment methods *e.g.*, trawling or trapping.

Discussion

Washington State Approach

The process used in Washington State to allocate crab and prawn resources between Tribal and State fisheries allows us to examine a working example of one approach to the problem. In both B.C. and Washington, the first priority is conservation. A major difference exists however, between the priorities assigned to the parties involved in the program. In B.C., the right to access to the resource by First Nations for FSC is second only to conservation. In times of resource shortage, commercial and recreational fisheries are curtailed to allow FSC needs to be met before closure for conservation is required. In Washington State, the identified harvestable surplus is divided equally between State and Tribes, and each party then allocates shares for their respective fisheries (*e.g.*, the State allocates between and regulates their commercial and recreational fisheries and the

Tribes allocate between and regulate their commercial and CS fisheries). Presented graphically, the two scenarios look like this:



Depending upon the timing of each fishery, the need to ensure that one party to the agreement is required to get their share may require that DFO be conservative when predicting harvestable surpluses, which may not maximize total production from the stock in question.

Catch Monitoring

If sector-specific allocations (*e.g.*, quotas) are part of final treaty agreements for Dungeness crabs and prawns, monitoring of all sectors (commercial, recreational and First Nation FSC) will be necessary to estimate the removal of target animals and to minimize overages. A catch monitoring program must be implemented to track allocations as well as gather information on fishing effort. Fishing location, depth, numbers retained, discards, weights, gear types, soak and haul times, etc should be collected so that they can be incorporated with other data sources. A framework for facilitating data sharing between agencies (DFO and First Nations) is essential. This would include data collection (at-sea observers, logbooks, etc.); data management (keypunching and storage); and reporting and analysis (i.e. landings updates, fishing activity summaries, etc). Key management decisions will rely on complete and accurate collection and timely reporting of data. Other fishing sectors would likely request a highly accurate accounting process or catch monitoring of FSC allocation, particularly if competition or conservation issues arise.

The Nisga'a Lisims government is using catch monitoring to obtain catch and effort data from Nisga'a citizens for non-salmon fisheries (Baxter and Azak 2003). The objective is to assist the Nisga'a in defining non-salmon entitlements as part of their Final Agreement. The catch monitoring program includes creel surveys and phone interviews.

Catch Reporting

The need for accurate catch reporting by all sectors (commercial, recreational and First Nations) will also be important if FSC allocations are based on historical production. The only current source of information on crab and prawn catches is from commercial fisheries landings. Estimates would be higher if First Nations and recreational catches were included. First Nations catch for Dungeness crabs and prawns are inaccurate or unknown although there are reporting requirements. Recreational catch for Dungeness crabs and prawns are unknown because catch reporting is not required. However, recreational and First Nations catch of crabs and prawns some areas are probably significant because they are socially important and highly sought after species; other information indicates that recreational use of crab and prawn has increased in recent years, particularly as fishing

opportunities for salmon decreased. It is therefore essential that catch reporting programs be developed for First Nations and recreational fisheries to ensure accurate estimates of total production.

As final treaty agreements are nearing completion, it would be wise to start implementing catch monitoring and reporting programs prior to the treaty process. Frameworks or guidelines should be developed outlining responsibilities for how catch information is collected and shared. Options for catch monitoring programs include creel surveys, voluntary logbooks, mandatory logbooks, hail systems, electronic monitoring, at-sea observer coverage and dockside validation.

Spatial Scale

Determining the appropriate abundance-based approach and spatial scale for prawns is difficult since none of the methods presented in the paper has been tested for shrimp. Boutillier and Bond (1999a) do suggest that if a quota system for prawns is adopted, the spatial scale should probably be very small because prawns do not generally move after settlement. More importantly, they suggest that if too large a spatial scale is used it raises the possibility of localized overfishing. The area would have to rely upon a meta-population process to provide the necessary recruitment for those that were overfished. They do point out that prawns have a free-floating, free swimming larval stage so it's possible that the concept of meta-populations that share larvae may apply to prawns. Therefore, when determining the appropriate abundance-based method and spatial scale, one needs to consider biological characteristics of the local population.

For Dungeness crabs, a mark-recapture study was successful at determining the legal male population and effectiveness of management strategies for Dungeness crabs in a large area (3,912 hectares) of the Nass River estuary (Alexander *et al*. 2003). Other abundance-based approaches have not been tested for Dungeness crabs so the spatial scale will be difficult to determine especially since Dungeness crab habitat can vary considerably from small estuaries and bays to large areas such as the Fraser River delta.

Consideration for spatial scales must also take into account the possibility of 'baiting-out' crabs from an area. 'Baiting-out' occurs when an area is purposely saturated with baited traps to attract crabs from adjacent areas. The Canada-US border in Boundary Bay between White Rock, B.C. and Blaine, Wa, is an example where Canadian fishers place traps along the border to attract or 'bait-out' crabs from the US side or vise versa. There are no physical boundaries to prevent the movement of crabs. This could have an effect on the reliability of using CPUE as an index of abundance or any other abundance estimation method. Many of the abundance-based methods rely on the assumption that a population is closed or that immigration is equal to emigration.

If fisheries managers and treaty negotiators are to consider abundance-based index methods as an allocation tool for Dungeness crabs and prawns, each will need to consider the biological characteristics and habitat area in relation to spatial scale for determining the most appropriate abundance-based method. Once the spatial scale has been determined, the abundance-based assessment method and costs will be easier to ascertain.

Conclusions and Recommendations

Each method described in this paper for allocating Dungeness crab or prawn resource has its own advantages and disadvantages (Table 10). The information provided is fairly general in nature and may not be appropriate for every area or each species. Final determination of the most successful approach will depend largely on the spatial scale, stock characteristics, dynamics of each fisheries sector, testing of assumptions and cost. This will likely mean a number of methods require testing and development over time. For example, commercial CPUE as an index of abundance for crabs might not work if multiple moults take place throughout the fishing season, so instead, mark-recapture programs might be better.

Also, fishing practices are constantly changing so some programs will need constant evaluation. The fixed escapement program for prawns is successful at preventing recruitment overfishing but is constantly evaluated and adjusted in response to changing fishing practices.

Timing is also an issue. Openings may need to be adjusted for moulting or soft-shell periods determined either through catch sampling or pre-season surveys. It is important to recognize that some programs require a decline commercial CPUE levels and therefore may create allocation problems later in the season as it becomes harder to capture animals when abundance has been reduced. Further complicating this matter is how to provide adequate opportunity to First Nations whose allocation requirements are throughout the year.

It's also unlikely either agency (DFO or First Nations) will have the capacity to develop any of the programs on its own. In order for any of the programs to succeed, partnerships (cost-sharing) and collaborations (information sharing among sectors) are necessary. A common component will be a catch monitoring or sampling programs. The Alexander *et al.* (2003) study is good example of cooperation between different fishing sectors (First Nations and Area B commercial crabbers) during the tag recovery and sampling components, and the Washington State experience demonstrates shared responsibilities and a collaborative approach to meeting conservation and allocation objectives.

It is important to note that abundance-based approaches are one of several allocation tools available to fisheries managers and treaty negotiators and regardless of what delivery options are used, the primary goal for all stakeholders is long-term sustainability of the resource. Additionally, options for allocation of crab or prawns should consider the risk level. In some cases, allocations derived from abundance-based models may not be necessary if the allocation amount is relatively small compared to the total harvest in the area. An abundance-based approach would not justify the cost considering issues regarding access are unlikely and there probably would be a low risk of overfishing. However, if the allocation amount is relatively large to the current estimate of catch in the area, justification for abundance-based approaches would be more appropriate because issues of allocation are more likely and there probably would be a higher risk to overfishing.

Frameworks or decision trees must be developed where harvest is based on biological thresholds. However, consideration for the appropriate allocation mechanism must be able to provide adequate abundance in a manner so First Nations will be able to best achieve their allocation aside for conservation concerns. For all of the assessment

models presented here (except for allocation based on historical production), each allows for proactive management action well in advance rather than reactive decision making.

Finally, one must be aware that much of the coastline will eventually become part of a treaty-defined FSC area, so the implications of different management strategies for each First Nations domestic fishing area and commercial and recreational fisheries need to be considered. Multiple assessment and management systems in different parts of the coast stemming from different treaty settlements would overly complicate the management of the species.

Recommendations

1. **Improve and develop catch monitoring and catch reporting programs for all Dungeness crab and prawn fisheries (commercial, recreational and First Nations FSC).** Current catch information for Dungeness crabs and prawns is incomplete, which limits the utility of estimates of historical catch as indicators of productivity of an area or stock. The abundance-based methods described in the paper require accurate estimates of total removals to track allocations, close sectors when allocations have been achieved, and to estimate total population size and exploitation rates.

2. **If abundance-based index methods are considered, then multiple programs should be initiated, developed and tested to determine which methods are most appropriate in each area prior to implementation of treaties.** Neither of these species is currently managed using estimates of total abundance, and there has been only limited experience with allocation tools. The most successful method in a given area will depend on stock characteristics, habitat area and relative dynamics of fisheries conducted by each sector. Because the "best" approach for each area cannot be determined *a priori*, sufficient data should be collected to evaluate a number of models, with the recognition that these programs require development over a number of years.

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References

Alexander, R.F., W.J. Gazey and I. Winther. 2003. Assessment of the Dungeness crab population in the Nass Estuary, 2000 and 2001. PSARC Working Paper I2003-05. 165 p.

Baxter, B.E. and C.G. Azak. 2003. Nisga'a non-salmon catch monitoring program: 2002. Nisga'a Lisims Fisheries Report No. NF02-06.

Bornhold, E., J. Morrison, G. Parker and K. West. unpubl. manuscr. Crab. Invertebrate fishery update (To December 2002). Fisheries and Oceans Canada, Vancouver.

Boutillier, J.A. 1986. Shrimp. p. 58-64. *In*: G.S. Jamieson and K. Francis [eds.]. Invertebrate and marine plant fishery resources of British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 91.

Boutillier, J.A. 1987. Prawn trap fishery and fishery monitoring. PSARC Working Paper S87-2.

Boutillier, J.A. and J.A. Bond. 1999a. Implications on assessment of the British Columbia prawn populations with the adoption of a quota management system. CSAS Res. Doc. 99/130. 13 p.

Boutillier, J.A. and J.A. Bond. 1999b. A progress report on the control of growth and recruitment overfishing in the shrimp trap fishery in British Columbia. CSAS Res. Doc. 99/202. 23 p.

Boutillier, J.A. and J.A. Bond. 2000. Using a fixed escapement strategy to control recruitment overfishing in the shrimp trap fishery in British Columbia. J. Northw. Atl. Fish. Sci., Vol. 27: 261-271.

Butler, T.H. 1960. Maturity and breeding of the Pacific edible crab, *Cancer magister* Dana, 1852. J. Fish. Res. Board Can. 17(5): 641-646.

Butler, T.H. 1961. Growth and age determination of the Pacific edible crab *Cancer magister* Dana. J. Fish. Res. Board Can. 18(5): 873-891

Butler, T.H. 1980. Shrimps of the Pacific Coast of Canada. Can. Bull. Fish. Aquat. Sci. 202: 280 p.

Butler, T.H. 1984. Dungeness crab. Underwater World. Fisheries and Oceans Canada, Ottawa. 4 p.

Butler, T.H. 1986. Crabs. p. 54-58. *In*: G.S. Jamieson and K. Francis [eds.]. Invertebrate and marine plant fishery resources of British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 91.

Chen, C.-L., J.M. Hoenig, E.G. Dawe, C. Brownie and K.H. Pollock. 1998. New developments in change-in-ratio and index-removal methods, with application to snow crab (*Chionoecetes opilio*). p. 49-61. *In*: G.S. Jamieson and A. Campbell [eds.]. Proceedings of the North Pacific symposium on invertebrate stock assessment and management. Can. Spec. Publ. Fish. Aquat. Sci. 125.

Claytor, R. and J. Allard. 2003. Change-in-ratio estimates of lobster exploitation rate using sampling concurrent with fishing. Can. J. Fish. Aquat. Sci. 60: 1190-1203.

Dawe, E.G., J.M. Hoenig and X. Xu. 1993. Change-in ratio and index removal methods for population assessment and their application to snow crab (*Chionoecetes opilio*). Can. J. Fish. Aquat. Sci. 50: 1467-1476.

DFO. unpubl. manuscr. Prawn and shrimp by trap (Pacific Region, July 2002). Fisheries and Oceans Canada, Vancouver.

DFO. 1999. Dungeness crab North Coast License Area A. DFO Science Stock Status Report C6-01(1999). 4p.

DFO. 2000. Dungeness crab, coastal fisheries, areas B, E, G, H, I & J. DFO Science Stock Status Report C6-14 (2000). 4 p.

DFO. 2004. Integrated fisheries management plan, prawn and shrimp by trap, May 1, 2004 to April 30, 2005. Pacific Region, Fisheries and Oceans Canada, Vancouver.

DFO. 2005. Integrated fisheries management plan, crab by trap, January 1, 2003 to December 31, 2005 (Revised 2005). Pacific Region. Fisheries and Oceans Canada, Vancouver.

Dunham. J.S., J.A. Boutillier, D. Rutherford and K. Fong. 2002. Biological decision rules for the assessment and management of directed fisheries on *Pandalus hypsinotus*, Humpback shrimp. CSAS Res. Doc. 99/202. 59 p.

Hart, J.F.L. 1982. Crabs and their relatives of British Columbia. B.C. Prov. Mus. Handbook 40. 267 p.

Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, London, U.K. 570 p.

INAC. 2004. Indian and Northern Affairs Canada. www.ainc-inac.gc.ca.

Kimker, A., W. Donaldson and W.R. Bechtol. 1996. Spot shrimp growth in Unakwik Inlet, Prince William Sound, Alaska. Alaska Fishery Research Bulletin 3(1): 1-8.

MacKay, D.C.G. 1942. The Pacific edible crab, *Cancer magister*. Bull. Fish. Res. Board Can. 62. 32 p.

MAFF. 2003. The British Columbia Seafood Industry in Review. BC Ministry of Agriculture, Food and Fisheries (MAFF). Victoria.

Martin, J.C. and K.L. Yamanaka. 2004. A visual survey of inshore rockfish abundance and habitat in the southern Strait of Georgia using a shallow-water towed video system. Can. Tech. Rep. Fish. Aquat. Sci. 2566: ix + 52 p.

Methot, R.D.Jr. and L.W. Botsford. 1982. Estimated pre-season abundance in the California Dungeness crab (*Cancer magister*) fisheries. Can. J. Fish. Aquat. Sci. 39: 1077-1083.

Morrison, J., M. Kattilakoski, I. Winther and J. Boutillier. 2002. *In*: R.M. Harbo and E.S. Wylie [eds.]. Pacific commercial fishery updates for invertebrate resources (1997). Can. Manuscr. Rep. Fish. Aquat Sci. 2586. 209 p.

Rutherford, D.T., L.L. Barton, G.E. Gillespie and J.A. Boutillier. 2004a. Utility of historical catch data in setting reference points for the British Columbia shrimp by trawl fishery. CSAS Res. Doc. 2004/026. 49 p.

Rutherford, D.T., H. Nguyen, and G.E. Gillespie. 2004b. Update on effort standardization for the in-season monitoring of the prawn by trap fishery. PSARC Working Paper I2004-01.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. 2nd ed. Oxford University Press, New York, NY. 654 p.

Smith, B.D. and G.S. Jamieson. 1989a. A model for standardizing Dungeness crab (*Cancer magister*) catch rates among traps which experienced different soak times. Can. J. Fish. Aquat. Sci. 46: 1600-1608.

Smith, B.D. and G.S. Jamieson. 1989b. Exploitation and mortality of male Dungeness crabs (*Cancer magister*) near Tofino, British Columbia. Can. J. Fish. Aquat. Sci. 46: 1609-1614.

Smith, B.D. and G.S. Jamieson. 1991. Movement, spatial distribution, and natural mortality of male and female Dungeness crab *Cancer magister* near Tofino, British Columbia. Fish. Bull. U.S. 89: 137-148.

Schwartz, C.J. and G.A.F. Seber. 1999. Estimating animal abundance: review III. Statistical Science. 14(4): 427-456.

Udevitz, M.S. and K. H. Pollock. 1991. Change-in-ratio estimators for populations with more than two subclasses. Biometrics. 47: 1531-1546.

WDFW. 2004a. North Puget Sound (Region 1) pandalid shrimp harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington State Dept. of Fish and Wildlife.

WDFW. 2004b. 2004-05 pandalid shrimp harvest management plan Region 2 East for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington State Dept. of Fish and Wildlife.

WDFW. 2004c. 2004-05 pandalid shrimp harvest management plan Region 2 West for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington State Dept. of Fish and Wildlife.

WDFW. 2004d. Region 3 (Strait of Juan de Fuca) pandalid shrimp harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004e. 2004-05 South and Central Puget Sound pandalid shrimp harvest management plan. Washington State Dept. of Fish and Wildlife.

WDFW. 2004f. 2004 Region 5 (Hood Canal) pandalid shrimp harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington State Dept. of Fish and Wildlife.

WDFW. 2004g. 2004-05 Region 1 Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004h. 2004-05 Region 2 East Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004i. 2004-05 Region 2 West Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004j. 2004-05 Region 3 Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004k. 2004-05 Region 4 Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004l. 2004-05 Region 5 Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

WDFW. 2004m. 2004-05 Region 6 Dungeness crab harvest management plan for fisheries conducted by U.S. v. Washington Subproceeding 89-3 Treaty Tribes and the State of Washington. Washington Dept. of Fish and Wildlife.

Weymouth, F.W. and D.C.G. MacKay. 1936. Analysis of the relative growth of the Pacific edible crab, *Cancer magister*. Proc. Zool. Soc. London 1936: 257-280.

Winther, I. and A. Phillips. 2002. Crab trap fisheries. P. 108-127. *In*: R.M. Harbo and E.S. Wylie [eds]. Pacific commercial fishery updates for invertebrate resources (1997). Can. Manuscr. Rep. Fish. Aquat. Sci. 2586.

Zhang, Z., W. Hagas, A. Phillips and J.A. Boutillier. 2002. Evaluation of an intensive fishery on Dungeness crab, *Cancer magister*, in Fraser Delta, British Columbia. CSAS Res. Doc. 2002/118. 58 p.

Zhang, Z., W. Hajas, A. Phillips and J.A. Boutillier. 2004. Use of length-based models to estimate biological parameters and conduct yield analyses for male Dungeness crab (*Cancer magister*). Can. J. Fish. Aquat. Sci 61: 2126-2124.

Table 1. Dungeness crab landings (t) by Crab Management Area, 1980-2002 (from Bornhold *et al*. unpubl. manuscr.).

Year	Management Area					Total
	A	B	C	D	E	
1980	901.0	107.0	215.0	252.0	226.0	1,701.0
1981	548.4	126.3	171.7	229.5	238.6	1,312.7
1982	257.3	78.8	127.4	260.5	274.5	998.5
1983	141.6	160.9	141.6	274.0	238.9	957.0
1984	152.3	141.8	277.5	340.9	243.1	1,155.6
1985	166.3	107.6	180.8	352.5	356.9	1,164.1
1986	219.0	98.9	261.0	321.2	419.4	1,319.5
1987	257.6	135.4	230.1	424.3	583.2	1,630.6
1988	378.6	139.6	225.3	456.3	308.1	1,507.9
1989	351.5	237.3	227.6	407.9	294.2	1,518.5
1990	777.7	275.2	314.6	414.6	347.3	2,129.4
1991	447.9	434.8	305.2	314.9	355.0	1,857.8
1992	1,600.3	418.5	362.0	447.1	505.8	3,333.6
1993	4,798.0	282.2	419.1	491.1	298.8	6,289.2
1994	4,272.5	354.8	537.2	445.9	384.9	5,995.3
1995	2,728.8	474.1	434.1	645.4	256.8	4,539.2
1996	3,362.8	405.5	575.7	401.6	272.5	4,930.7
1997	2,110.3	225.6	562.7	502.2	470.5	3,871.3
1998	1,113.6	170.6	613.6	584.8	491.9	2,974.5
1999	1,464.8	165.4	520.3	539.4	258.3	2,948.5
2000	928.3	185.3	688.0	554.9	433.7	2,790.2
2001	3,301.8	181.3	841.3	689.0	630.1	5,643.5
2002	1,782.5	225.6	892.6	508.5	514.9	3,924.1

Notes: Data previous to 1988 include all species of crab.
Prior to 1990 landings are reported by Pacific Fisheries Management Areas (PFMAs) with the following breakdown, Area A = PFMA 1 & 2, Area B = PFMA 3 to 10 inclusive, Area C = PFMA 11 to 19 inclusive, Area D = PFMA 28 & 29, Area E = PFMA 20 to 27 inclusive.
Offshore catch of 7.6 tonnes in 1990 was included in Area E.
Landings after 1990 are reported by area selected, not by PFMA reported on fish slips due to reporting errors.

Table 2. Commercial prawn trap landings (t), 1980-2001 (from DFO, unpubl. manuscr.).

Year	Landings (t)				
	Total Coast	Northern Coast	Southern Coast	ECVI	WCVI
1980	361	104	257	219	38
1981	320	116	203	150	53
1982	264	72	191	110	81
1983	325	123	201	178	23
1984	377	96	279	240	39
1985	509	99	409	382	27
1986	543	127	414	389	25
1987	616	175	440	383	56
1988	714	242	473	403	70
1989	805	224	581	471	110
1990	757	130	627	552	75
1991	954	200	755	661	94
1992	1,166	280	883	771	112
1993	1,211	325	885	773	112
1994	1,307	446	861	736	125
1995	1,329	441	888	762	127
1996	1,715	641	1,074	971	103
1997	1,785	389	1,396	1,287	109
1998	1,734	386	1,347	1,244	103
1999	1,462	416	1,046	973	73
2000	1,748	465	1,284	1,184	99
2001	2,095	356	1,738	1,596	143

Notes: Landings from 1980-1994 are from sales slips, landings from 1995-2001 are from harvest logs.
Northern Coast includes PFMA 1-11, 101102, 105-108, 110 and 111.
Southern Coast includes PFMA 12-29, 123, 124 and 127.
ECVI includes PFMA 12-19, 28 and 29.
WCVI includes PFMA 20-27, 123, 124 and 127.

Table 3. Shrimp fishing seasons in Puget Sound, Washington State.

Region	Fishery	Opening Date	Closing Date	Comments
1	State and Tribal Commercial Pot (spot shrimp)	April 16	September 15	April 12 if extreme tides, Areas 1A and 1B fished separately
1	State Recreational and Tribal CS (spot shrimp)	April 16	October 15	
1A	State and Tribal Commercial Pot (non-spot shrimp)	May 1	October 15	May 1 or when spot shrimp shares reached, whichever is later
1B	State and Tribal Commercial Pot (non-spot shrimp)	May 1	October 15	
1	State and Tribal Shrimp Trawl	May 16	October 15	
2E	All Pot (spot shrimp)	April 1	September 15	
2E	State Recreational and Tribal CS (non-spot shrimp)	April 16	October 15	
2E	State and Tribal Commercial Pot (non-spot shrimp)	May 1	October 15	Maximum depth 175 ft (53 m) when spot shrimp closed
2W	All Pot (spot shrimp)	April 16	September 15	
2W	State Recreational and Tribal CS (non-spot shrimp)	April 16	October 15	
2W	State and Tribal Commercial Pot (non-spot shrimp)	May 1	October 15	
3	State and Tribal Commercial Pot (spot shrimp)	April 16	September 15	23AC fished separately from 23AE and 23AW, may extend beyond September 15 if ovigery allows
3	State Recreational and Tribal CS (all shrimp)	April 16	October 15	
3	State and Tribal Commercial Pot (non-spot shrimp)	May 1	October 15	In 23A, May 1 or when spot shrimp share reached, whichever comes first
3	State and Tribal Shrimp Trawl	April 16	October 15	Weekly sampling for count and ovigery
4	State and Tribal Pot (all shrimp)	April 16	September 15	All shrimp closed when spot shrimp share reached
5	All Pot (spot shrimp)	April 22	August 31	State and Tribal fisheries on different days, catches from 27A not to exceed 55% of harvest share
6	State and Tribal Pot (all shrimp)	April 16	October 15	

Table 4. Dungeness crab soft-shell closures in Puget Sound, Washington State.

Region	Area	Closing Date	Opening Date
1	San Juan (22A, 20B)	March 1	June 15
1	Bellingham/Samish (21A, 21B and 22B)	March 15	June 15
1	Strait of Georgia (20A)	April 15	August 15
2E	Zones 1 and 2 (24A, 24C, 24D, portions of 24B and 26AE)	February 15	June 1
2E	Zone 3 (portions of 24B and 26AE)	December 31	June 1
2W	2W	March 1	May 31
3	3	March 1	May 31
4	4	March 1	May 31
5	5	March 1	May 31
6	6	March 1	May 31

Table 5. Dungeness crab fishing seasons in Puget Sound, Washington State.

Region	Fishery	Opening Date	Closing Date	Comments
1	Tribal Commercial (Summer)	June 1	September 15	
1	Tribal Commercial (Fall/Winter)	October 1	April 15	
1	Tribal CS	Hard shell	Allocation	
1	State Commercial (Fall/Winter)	October 1	April 15	
1	State Recreational	Hard shell	Allocation	
2E	Tribal Commercial and CS	June 1	September 20	3.5 day pulse fishery
2E	State Commercial (Summer)	June 1	Allocation	
2E	State Commercial (Fall/Winter)	October 1	Allocation	
2E	State Recreational	June 1	September 7	Weekends only
2W	Tribal Commercial and CS	June 1	February 28	
2W	Tribal Commercial (Port Townsend Bay)	June 1	June 30	
2W	State and Tribal Commercial (Useless Bay)	September 16	February 28	
2W	State Commercial	September 16	February 28	
2W	State Recreational	June 1	February 28	
3	Tribal Commercial and CS (3-1)	June 16	February 28	
3	Tribal Subsistence (3-2)	June 16	February 28	
3	Tribal Commercial (3-2)	June 21	February 28	
3	Tribal Commercial and CS (3-3)	June 1	February 28	
3	State Recreational (3-1, 3-2)	June 16	February 28	
3	State Recreational (3-3)	June 1	February 28	
3	State Commercial	September 16	February 28	
4	All fisheries	June 1	February 28	
5	All fisheries	June 1	February 28	
6	All fisheries	June 1	February 28	
6	Tribal Commercial (Quartermaster Harbour)	August 1	February 28	
6	Tribal Commercial (Wollochet Bay)	August 1	February 28	

Table 6. Advantages and disadvantages of using historical catch data as a means for setting allocation.

Pro's	Con's
- Relatively inexpensive. Industry collects and reports the data.	- Requires accurate catch reporting by commercial, recreational and First Nation fishers.
- Information is readily available and easily computed.	- Catch information for Dungeness crabs and prawns are incomplete. Catch is only available from commercial fisheries. Recreational and First Nation catch is unknown for Dungeness crabs and prawns.
- The information is easily understood and easy to implement.	
- Catch monitoring requirements are relatively inexpensive. Mandatory logbooks or dockside monitoring to ensure quota is not exceeded.	- Historical catch is a poor means to tracking abundance. Not linked to current stock abundance.

Table 7. Significant management changes in the British Columbia prawn by trap fishery (DFO unpubl. manuscr.)

Year	Management Change
1979	Spawner index management commences.
1983	Harvest log requirement established.
1988	Minimum mesh size implemented; Minimum size limit of 30 mm implemented.
1989	Licence limitation implemented.
1993	Daylight fishing only, 5 hours before dawn and after sunset.
1995	Trap limitation initiated for 2 year pilot program; 300 traps or 450 for 2 (max.) stacked licences.
1996	Minimum size limit increased to 32 mm.
1997	Trap limitation pilot extended 1 year; logbook format changed. Minimum size limit increased to 33 mm. Release of berried female required until June 30. Saanich Inlet fished to 25% higher spawner index to maintain recreational fishing opportunity following the commercial fishery.
2000	Daily single haul limit in southern waters from 7 a.m. to 7 p.m. Trap limits increased to 500 traps for stacked licences; Saanich Inlet and important recreational areas fished to index +25%; all other coastal areas fished to index +10%.
2001	Daily single haul limit extended coast-wide.

Table 8. Estimated mean catch-per-unit-effort (CPUE, number of shrimp ± SD) of humpback shrimp, *Pandalus hypsinotus*, by sexual condition and trap type, Drury Inlet, November 2001 (Dunham *et al*. 2002).

Habitat	Reproductive Status	Trap Type	
		MM[1]	SM[2]
Trawlable – Main Inlet	Non-egg[3]	3 ± 3	13 ± 10
	Egg[4]	76 ± 39	119 ± 47
	Total[5]	0 ± 1	5 ± 5
Rocky – Main Inlet	Non-egg	0 ± 1	5 ± 5
	Egg	30 ± 33	39 ± 40
	Total	31 ± 34	44 ± 41
Upper Inlet	Non-egg	1 ± 2	6 ± 4
	Egg	25 ± 27	29 ± 36
	Total	26 ± 28	35 ± 38
All Inlet	Non-egg	1 ± 2	9 ± 8
	Egg	47 ± 42	65 ± 55
	Total	49 ± 43	73 ± 59

[1]Medium mesh
[2]Small mesh
[3]Non-egg = immature, male, and transitional (stages 0-2)
[4]Egg = female: not gravid, gravid and spent (stages 3-5)
[5]Total = all humpback shrimp

Table 9. Monthly Spawner Index. From Prawn and Shrimp by Trap – Fishery Update (DFO Pacific Region unpubl. report)

Month	Original Baseline	2000/2001 Coastal Target Index	Recr. & Spec. Mgmt. Areas (i.e. Saanich Inlet)	Sexual Class Included in Spawner Index Calculation
	Spawner Index	Target Index at +10%	Target Index at +25%	
Apr	6.4	7.0	8.0	all 2's and 3's
May	5.9	6.5	7.4	all 2's and 3's
Jun	5.4	5.9	6.8	all 2's and 3's
Jul	4.9	5.4	6.1	all 2's and 3's
Aug	4.4	4.8	5.5	all 2's and 3's
Sep	4.1	4.5	5.1	all 2's, 3's, and 4's
Oct	3.6	4.0	4.5	all 3's and 4's; (sex 2s have grown to sex 3s)
Nov	3.2	3.5	4.0	all 3's and 4's
Dec	2.7	3.0	3.4	all 4's; (sex 3s have all become berried up)
Jan	2.4	2.6	3.0	all 4's and 5's
Feb	2.0	2.2	2.5	all 4's and 5's
Mar	1.7	1.9	2.1	all 4's and 5's

Note: Sexual class codes are 2 = transition, 3 = females with no eggs, 4 = female with eggs, 5 = spent females.

Table 10. Summary of assessment options, data requirements and assumptions for Dungeness crabs and prawns.

Assessment Option	Data Requirements	Assumptions
1) Fishery dependent CPUE		
- Indices of abundance are based on commercial CPUE. - Harvest rates are applied to commercial CPUE at the beginning of the fishery to establish quotas and shutoff points.	- Commercial CPUE data needs to be collected at the beginning of the fishery to set target shutoff points. - In-season catch sampling to monitor target shutoff points and to collect catch composition information. - CPUE targets over time need to be modeled in manner that distinguishes between declines due to natural mortality and fishing mortality. - Standardization of trap gear and soak times are necessary.	- Fishing adequately covers the area. - Population is closed or immigration and emigration are equal. - Fishing takes place during non-moulting periods. - Natural mortality of legal-size male crabs is offset by undersize male crabs moulting to legal-size. - All crabs above legal-size have the same probability of capture.
2) Fishery independent CPUE		
- Index of abundance based on fishery independent CPUE. - Harvest rates are applied to a pre-season CPUE to establish catch levels.	- Requires pre-season research survey to establish CPUE index. - Requires commercial CPUE to be weighted (correction factors) against fishery independent CPUE. - If commercial CPUE is not used to monitor the fishery, then repeated in-season surveys are necessary to monitor shutoff points. - Standardized fishing methods and locations are necessary.	- Sampling adequately covers the area. - Population is closed or immigration and emigration are equal. - Sampling takes place during non-moulting periods. - Natural mortality of legal-size male crabs is offset by undersize male crabs moulting to legal-size. - All crabs above legal-size have the same probability of capture.

Table 10. Continued.

Assessment Option	Data Requirements	Assumptions
3) Change-in-Ratio		
- Change-in-ratio methods can be used when removals from a closed population significantly change the proportions of animals in two or more classes. - Natural classes are size, sex, age etc. - Total abundance and exploitation rates can be estimated.	- Requires pre- and post fishery research surveys. - In-season catch sampling. - Catch monitoring program to track quotas.	- Population is closed (immigration and emigration are equal) except for removals. - Natural mortality and moulting is equal. - Each animal has the same probability of capture.
4) Index Removal		
- If CPUE is proportional to abundance, and if a known removal causes CPUE to decline by a specified proportion, then the removal is equal to the proportion of the population. - Total abundance and exploitation rates can be estimated.	- Requires pre- and post fishery research surveys. - In-season catch sampling. - Catch monitoring program to track quotas.	- The population is closed or, alternatively additions equal losses (excluding removal). - Each animal has the same probability of capture.
5) Mark-recapture studies		
- Tagging studies are useful for estimating abundance, movement, harvest rates, and growth.	- Requires sufficient sampling for capture, mark and recapture of animals. - A tag reward program to encourage tag returns or onboard catch sampling. - Catch monitoring program to track quotas.	- Animals are not affected by tagging or tags will not be lost. - Marked animals completely mix with unmarked animals. - Marked animals have the same probability of capture as unmarked animals. - All marks are reported when recaptured.
6) Video Assessment		
- Underwater camera towed behind a vessel. - Density estimates may be possible. Has been used for estimating abundance of rockfish.	- Area can be determined from calibrations in the field of view of the camera. - Lasers used to estimate size of animal.	- Camera can towed over all types of habitats. - All animals are visible. Dungeness crabs have the ability to bury themselves. Prawns can hide in crevices of rocks.

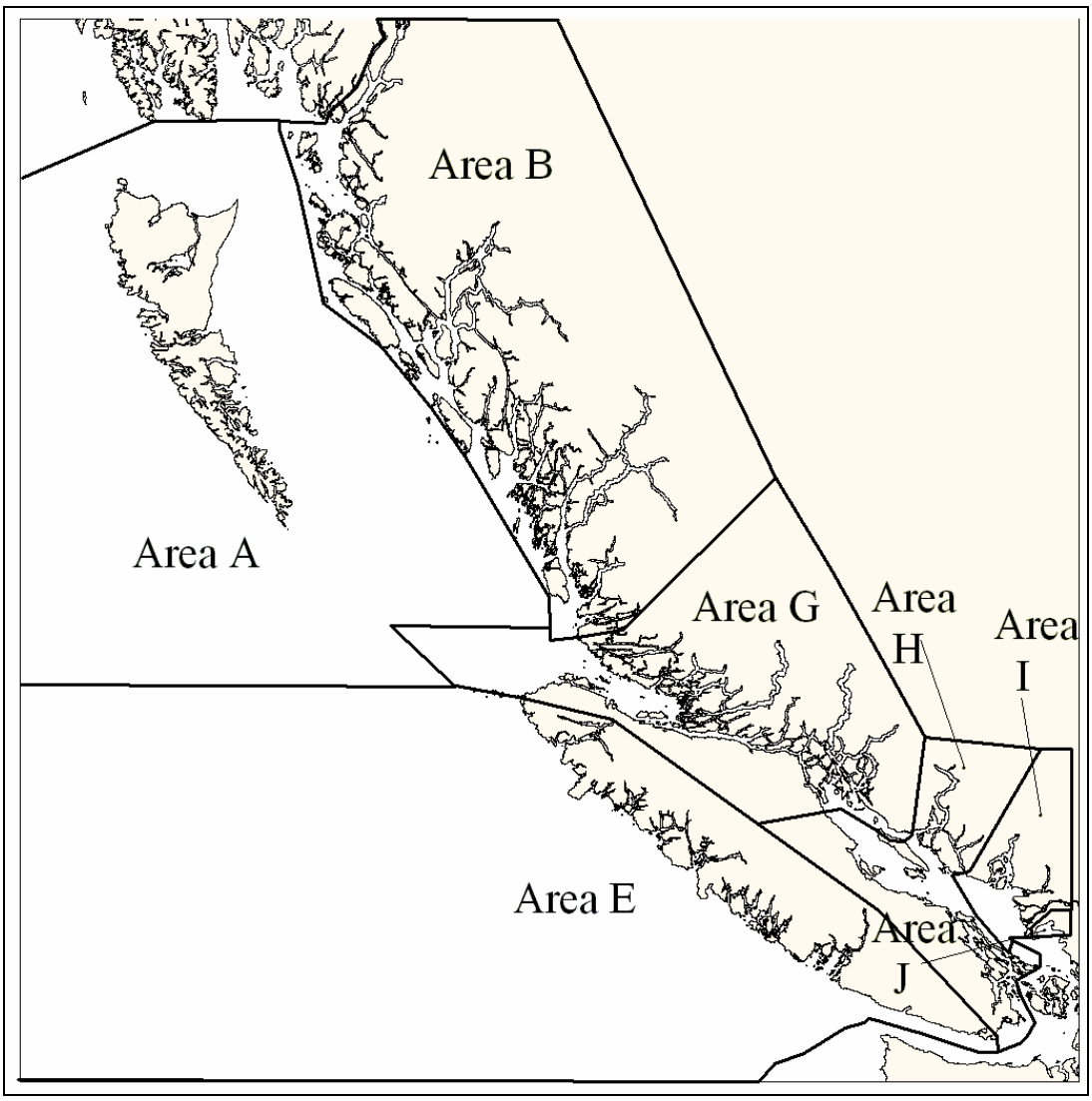


Figure 1. Commercial crab licence areas in British Columbia.

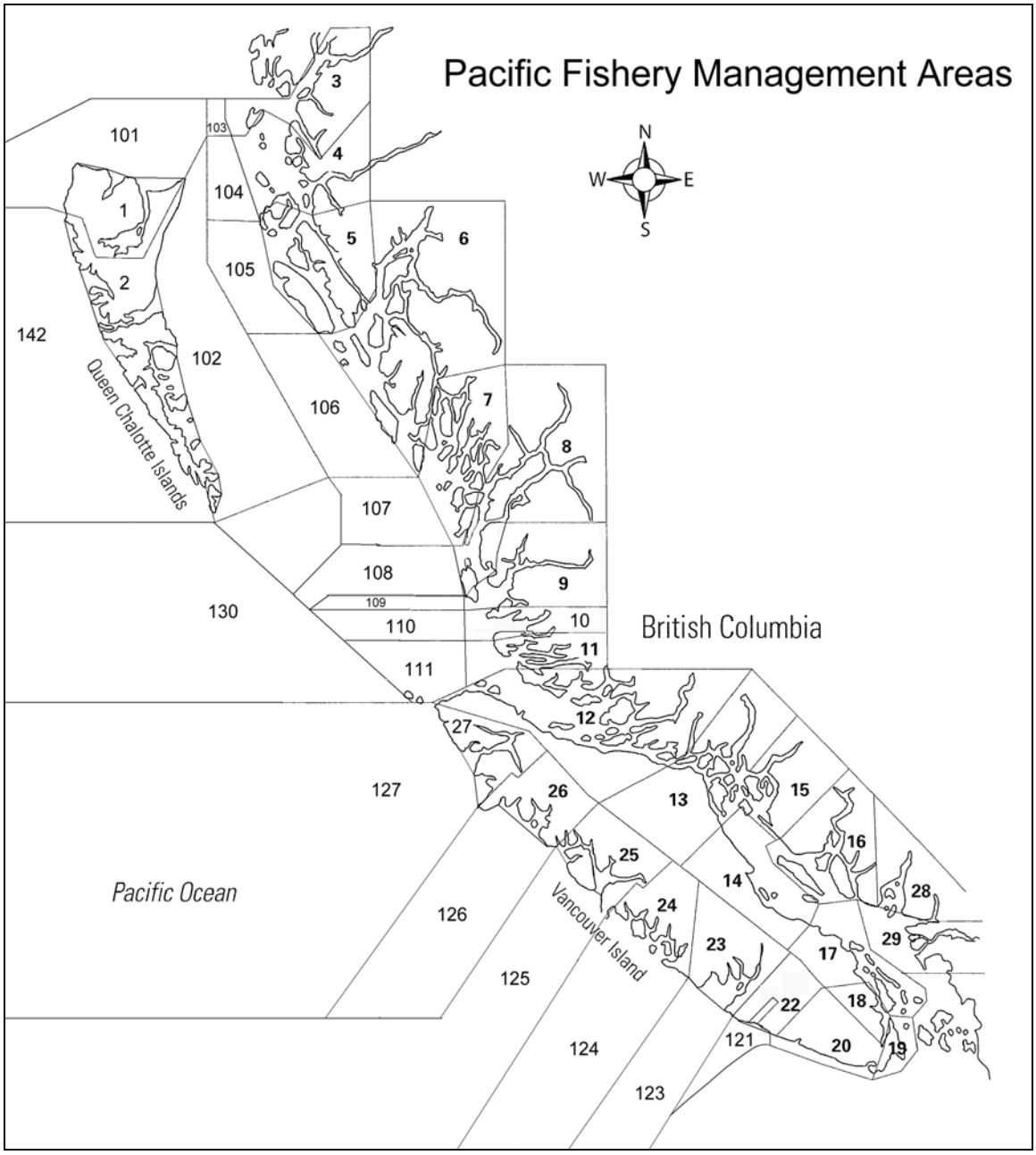


Figure 2. Pacific Fishery Management Areas for British Columbia.

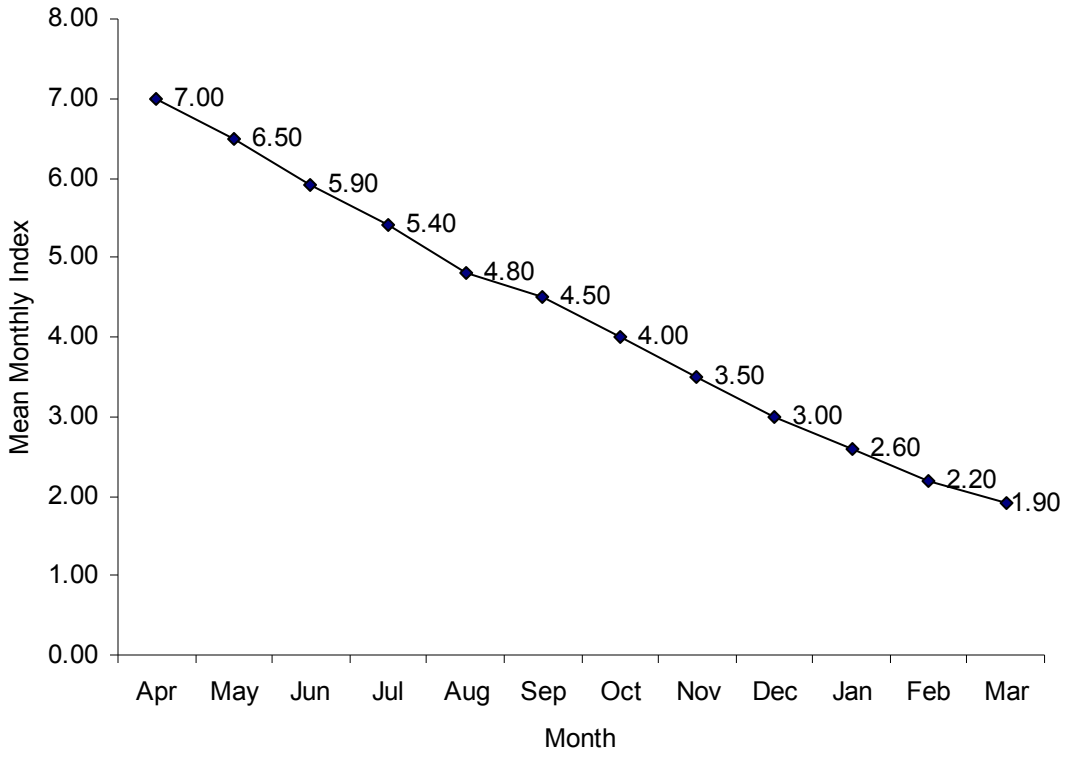
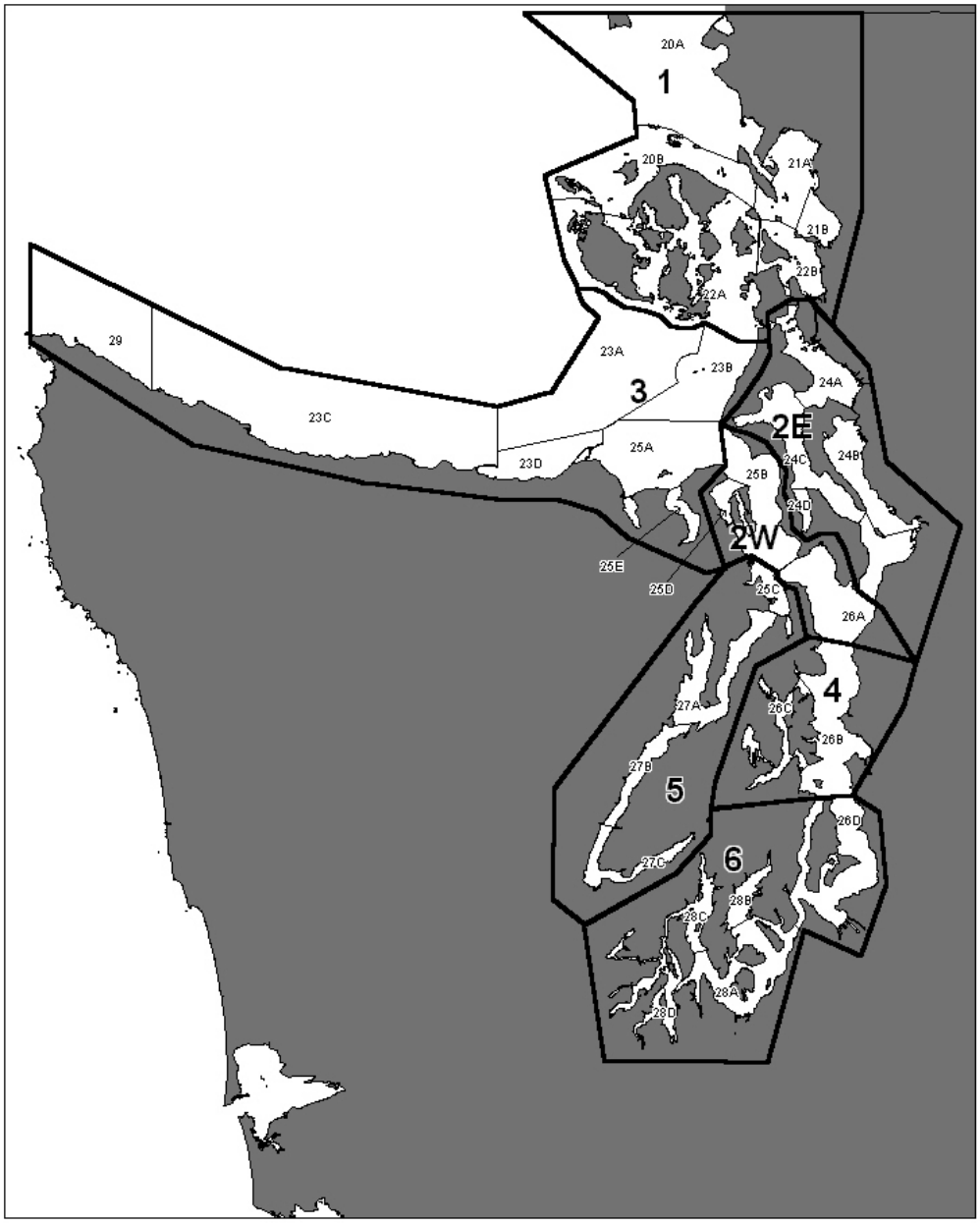


Figure 3. Monthly target spawner index for British Columbia prawn trap fisheries.



PUGET SOUND CRUSTACEAN MANAGEMENT REGIONS
AND CORRESPONDING MFSF CATCH AREAS As of June 1, 2001

Figure 4. Crustacean management areas and catch areas, Puget Sound, Washington State.

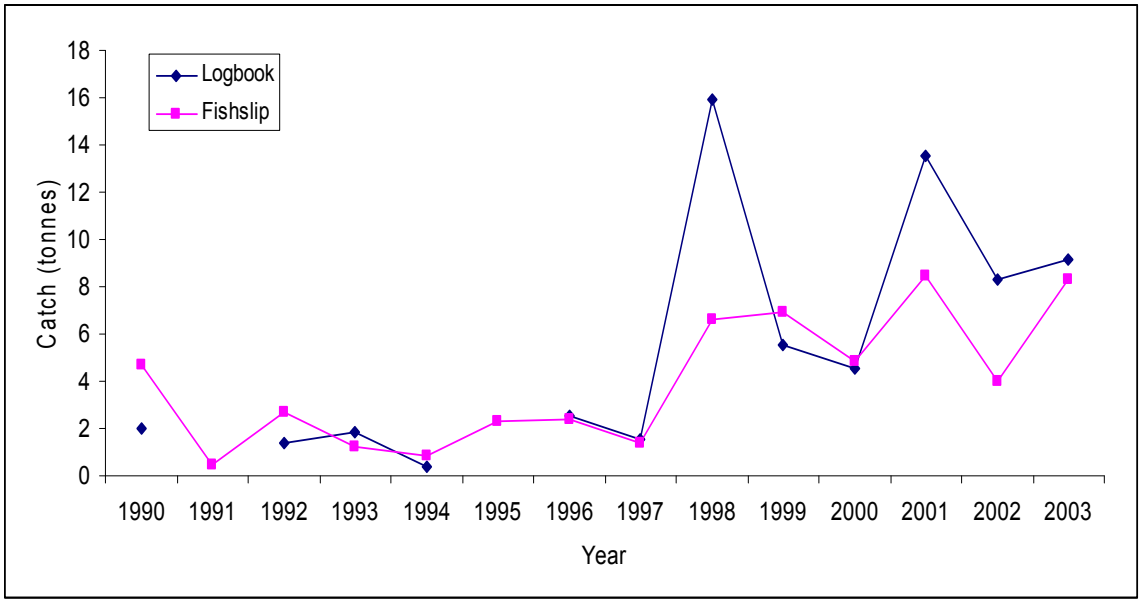


Figure 5. Comparison of commercial crab landings by data source by year from PFMA 23 (Barkley Sound). Commercial logbook data and fish slip data.

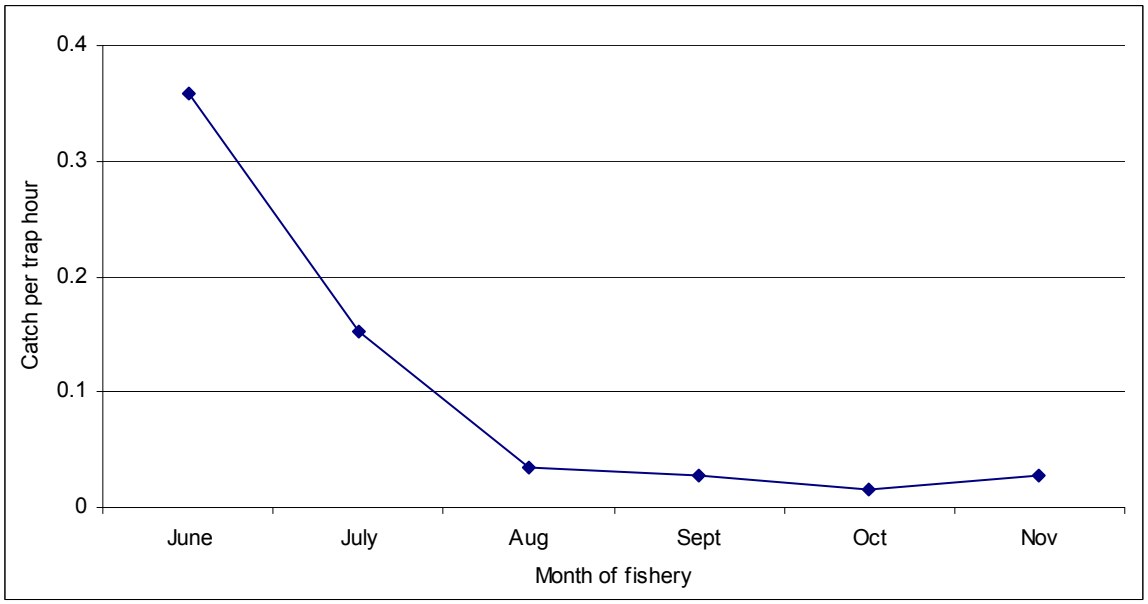


Figure 6. Decline in CPUE of legal-size male Dungeness crabs in the 2004 Fraser Delta commercial fishery.
Source: 2004 commercial logbook data.

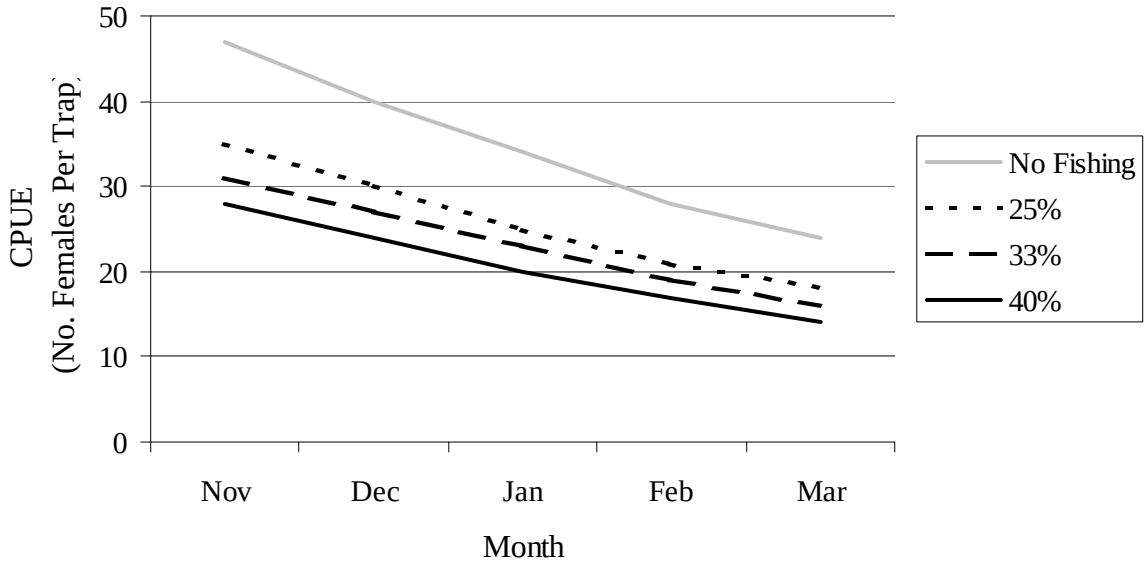


Figure 7. Total allowable catches (TACs) for a humpback shrimp trap fishery in Drury Inlet, British Columbia, based on fishery-dependent CPUE of female shrimp. Target CPUE estimates are derived from 25%, 33%, and 40% harvest rates applied to survivors each month. (Dunham *et al.* 2002).

Appendix 1

PACIFIC SCIENTIFIC ADVICE REVIEW COMMITTEE (PSARC)
INVERTEBRATE SUBCOMMITTEE

Request for Working Paper

Date Submitted: April 2005

Individual or group requesting advice:
- *Jennifer Nener, Treaty Negotiator, DFO Treaty and Aboriginal Policy Branch.*

Proposed PSARC Presentation Date: April 2005

Subject of Paper (title if developed): Evaluation of abundance based index methods for Dungeness crab, *Cancer magister*, and spot prawn, *Pandalus platyceros*, on small spatial scales.

Science Lead Author: Ken Fong

Resource Management Lead Author:

Rationale for request:
- This paper will provide the scientific advice to treaty negotiators and managers when considering the domestic allocation delivered under treaties to First Nations for Dungeness crabs and prawns.

Objectives of Working Paper:
- This paper will evaluate abundance based index methods for Dungeness crabs and prawns on small spatial scales.
- To evaluate catch information for Dungeness crabs and prawns.
- This paper will define data requirements and present other considerations for the potential options.

Question(s) to be addressed in the Working Paper:
- What are the options available to treaty negotiators and managers for delivering domestic allocations to First Nations under treaties for Dungeness crabs and prawns?
- What are the biological considerations and data requirements?
- What are the advantages and disadvantages in terms of data requirements for implementing each model? What is the spatial scale?
- How effective will each model be in providing First Nation domestic allocation through treaties (by area)?

Stakeholders Affected:
- First Nations, commercial fishing and recreational fishing sectors.

How Advice May Impact the Development of a Fishing Plan:

- This will give managers and treaty negotiators options to consider when deciding upon FSC allocations to First Nations under treaties for Dungeness crabs and prawns.
- Fishing plans will likely be altered with the implementation of final treaty agreements.

Timing issues related to when Advice is necessary:

- Several First Nations groups are nearing the finalization of treaties.
- A PSARC paper in April 2005 will provide managers and treaty negotiators the necessary information to negotiate First Nations domestic fishing allocations for Dungeness crabs and prawns.

Approval:

Regional Director Fisheries Management _____ Date:_____

Regional Director Science _____ Date:_____