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Pandalus hypsinotus, Humpback Shrimp A Review of the Biology and a Recommended Assessment Framework for a Directed Fishery

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Abstract

At the direction of the Minister of Fisheries and Oceans any expansion of a fishery for humpback shrimp, *Pandalus hypsinotus,* into non-traditional areas or with new or modified trawl or trap gear will be subject to the Pacific Region Guidelines on New and Developing fisheries (Pacific guidelines). This paper provides the first step in meeting the principles outlined in the Pacific guidelines. The paper presents a review of what is known about the biology and the fishing history of these animals around the world. From this review, the paper then goes on to suggest an appropriate assessment and management framework for the development of a directed fishery in British Columbia.

The important aspects of the biology that the assessment framework must address will include variable growth rates between areas, ability of the animals to produce primary females, and potential multiparous nature of these animals. The important aspects of the fisheries that need to be considered when developing a management framework include: 1) the inability to develop guidelines for escapement targets for these animals without a history of fishing and recruitment success and 2) the difficulties that all other nations have had with developing a sustainable fishery for this species.

The paper concluded that there was potential within B.C. coastal waters for targeted humpback shrimp fisheries. There were a number of suggestions on how this fishery may go forward under a precautionary framework. The key aspects to the precautionary framework included: removal of specific areas from the other trap and trawl shrimp fisheries; recommended target and limit reference points; and adoption of experimental management approach to address knowledge gaps e.g. assessment methodologies, appropriate exploitation levels, reproductive potential, etc.

Résumé

À la demande du Ministre des Pêches et des Océans, toute expansion d'une pêcherie de la crevette à front rayé, *Pandalus hypsinotus*, dans des secteurs non traditionnels de pêche ou avec des engins modifiés ou nouveaux (chaluts, casiers), sera soumise aux lignes directrices de la Région du Pacifique sur les pêches nouvelles et en développement. Ce document présente les premières étapes nécessaires au respect des principes exposés dans les lignes directrices du Pacifique. Ce document effectue un survol des connaissances actuelles de la biologie et de l'historique des pêches de ces espèces dans le monde. Suite à cet examen, on propose un cadre d'évaluation et de gestion approprié pour le développement d'une pêche dirigée en Colombie-Britannique.

Le cadre d'évaluation doit comprendre les aspects importants de la biologie de cette espèce, y compris le taux de croissance variable entre les zones, la capacité des animaux à produire des femelles primaires, et la nature multipare potentielle de ces animaux. Lors de l'élaboration d'un cadre de gestion, on devra tenir compte des aspects importants des pêches suivants : 1) l'incapacité d'élaborer des lignes directrices pour les objectifs d'échappée de ces animaux en l'absence de données sur l'historique des pêcheries et le succès du recrutement et 2) les difficultés que toutes les autres nations ont éprouvées lorsqu'elles ont élaboré une pêche durable de cette espèce.

Ce document conclut qu'il existe un potentiel pour la pêche dirigée de la crevette à front rayé dans les eaux côtières de la Colombie-Britannique. Un bon nombre de suggestions ont été faites quant à la manière dont cette pêche peut prendre son essor dans le cadre d'une approche de précaution. Les éléments-clés de cette approche de précaution comprennent : l'interdiction de certaines zones spécifiques aux autres pêches à la crevette effectuées au casier et au chalut, les recommandations d'objectifs et de points de référence limites et l'adoption d'une approche de gestion expérimentale pour combler les lacunes des connaissances, c'est-à-dire les procédures d'évaluation, les niveaux d'exploitation pertinents, le potentiel reproducteur, etc.

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Introduction

The Minister of Fisheries and Oceans, has directed that "any directed fishery for humpback shrimp, *Pandalus hypsinotus,* in non-traditional areas or with new or modified trawl or trap gear will be subject to the Pacific Region Guidelines on New and Developing Invertebrate fisheries". As part of the process for establishment of new and developing Invertebrate fishery, managers solicited this report to develop a biological basis for the management of a fishery on Humpback shrimp, *Pandalus hypsinotus*.

The Pacific Region Shellfish Stock Assessment Section adopted a framework for provision of scientific advise for management of new and developing fisheries to compliment the Pacific Region Guidelines on New and Developing Invertebrate fisheries. Perry et al (1999) describes this framework which entails a phased approach to the provision of advice.

- Phase 0: Assimilation of all known data and information in the literature on the target species or closely related species. This phase should outline what is known and what needs to be known before a fishery develops. The data requirements will depend on the management approach that is adopted: fixed escapement, fixed exploitation or fixed quota.
- Phase 1: Development of a framework for collecting the data required to address the gaps in knowledge highlighted in Phase 0.
- Phase 2: Development of a fishery to allow it to expand to its full commercial potential.

Managers have received repeated requests for access to this resource from both the shrimp trap and shrimp trawl industries. The urgency of the request, from the industry perspective, results from an unprecedented growth in the effective effort in the directed trap and trawl fisheries for shrimp in British Columbia waters. The shrimp trap fishery feels that a significant opportunity is foregone through the current shrimp trap fishery, which only allows humpback shrimp to be exploited incidentally during the prawn trap fishery openings. The shrimp trawl fishery is in a process of rapid expansion of exploitation of small previously unexploited populations of shrimp. They presently harvest humpback shrimp as part of the overall quota within a mixed shrimp stock fishery. Exclusion of humpback shrimp areas from new areas of exploitation is felt to be a hindrance to their fishery development.

Shrimp Fisheries in British Columbia

There are in excess of 87 species of shrimp in British Columbia (B.C.) waters. Of these, there are seven commercial species of shrimp harvested in the B.C. shrimp trap and trawl fisheries. All seven of these species belong to two genera in the family *Pandalidae*. Table 1 below identifies the seven commercial species exploited in the trap and trawl fisheries along with their latitudinal range, depth ranges, and general location in B.C. waters.

Scientific Name	*Common Name in B.C.*	*Geographic range in Pacific basin, Depth range and range in B.C. waters (Butler 1980).*	*Fishery (Boutillier and Joyce 1998, Butler 1980).*
Pandalus platyceros	Spot prawn	Range in eastern Pacific from San Diego CA to Unalaska Island AK and in the western Pacific in Sea of Japan and Korea Strait. Intertidal to 487 m. Most abundant in British Columbia in the protected inside waters although they do occur in offshore regions.	Directed trap fishery in inshore waters coastwide. Incidentally caught in trawl fishery with bycatch limits. Most valuable shrimp fishery in B.C.
P. borealis eous	Northern pink shrimp	Range in eastern Pacific from St. Matthew Island to Columbia River and in the western Pacific from Seas of Japan to the Okhotsk Sea. 16-1380 m In B.C. most of the population are in protected inshore waters or nearshore areas in the north coast.	Series of small-directed trawl fisheries in inshore and nearshore areas of B.C. Associated with small relatively stable populations, which in some areas have had fisheries since the early 1900's.
P. jordani	Smooth pink shrimp	Range in eastern Pacific from Unalaska Island AK to San Nicholas Island, CA. 36-457 m In B.C. major populations occur in offshore and nearshore regions of the coastal waters ranging from West Coast of Vancouver Island, Queen Charlotte Sound, Chatham Sound and some inshore areas in the Georgia Straits.	Directed trawl fishery in offshore areas of B.C. Makes up the bulk of target species in the trawl fishery but is associated with large fluctuations in abundance.
P. goniurus	Flexed Pandalid	Chukchi Sea; Bering Sea to Puget Sound; Okhotsk Sea; Sea of Japan. 5-450m In B.C. small isolated populations occur in inshore and nearshore regions	Small almost negligible incidental catch in the inshore, nearshore trawl fisheries for shrimp.
P. hypsinotus	Humpback shrimp	In the eastern Pacific from Norton Sound AK to Puget Sound WA. In the western regions from western Bering Sea to the Sea of Japan and Korea Strait. 5-460m In B.C. water the distribution is small isolated populations associated with protected inshore waters in inlets.	Incidental catches in both the trap and trawl fisheries with small, directed trap fisheries occurring in Masset Inlet and Prince Rupert Harbour and a small, directed trawl fishery in the Knight Inlet area. This species reported for years as Coonstripe shrimp in the northern fisheries.
P. danae	Coonstripe or Dock shrimp	Resurrection Bay, AK to Point Loma, CA. Intertidal to 185 m In B.C. predominantly occur in small isolated populations in	Incidental catches in both the trap and trawl fisheries with a small, directed trap fishery in Area 20 and newly developed directed trawl fisheries

		inshore areas.	occurring in Areas 18 and 19.
Pandalopsis dispar	Sidestripe shrimp	Pribilof Islands, Bering Sea, to Manhattan Beach, OR. 46-649 m In inshore, nearshore and offshore regions of B.C. coast. Highest densities appear to be in the inshore regions.	Mainly has been an incidental catch in the shrimp trawl although the industry is now experimenting with the technology to target on this species.

Table 1: A summary of the range and types of fisheries exploiting the commercial species of Pandalid shrimp in B.C. coastal waters.

Fisheries Biology of Pandalid shrimp

Taxonomy

All the commercial species of shrimp in B.C. waters belong to the Family Pandalidae. Members of this family of shrimp are distributed in all the worlds' oceans. The family is divided into eighteen genera (Butler 1980, Rupert and Barnes 1994). In British Columbia there are ten known species of shrimp belonging to two genera. Detailed taxonomy is shown below.

Phylum Arthropoda
- *Subphylum Crustacea*
- *Class Malacostraca*
  - *Order Decapoda*
  - *Suborder Pleocyemata*
    - *Infraorder Caridea*
      - *Family Pandalidae*
        - *Genus Pandalus*
          - *Pandalus borealis eous*
          - *P. danae*
          - *P. jordani*
          - *P. goniurus*
          - *P. hypsinotus*
          - *P. platyceros*
          - *P. stenolepsis*
          - *P. tridens*
        - *Genus Pandalopsis*
          - *Pandalopsis dispar*
          - *P. lucidirimicola*

Pandalid shrimp Life History

Pandalid shrimp start their lives as larvae that hatch in the spring. The number of stages and the morphology of the larvae vary considerably between species. The rate of development through these stages seem to be affected by environmental conditions such as temperature but generally the larvae remain in the water column for 2 to 3 months. Although the larvae differ considerably between the various species of Pandalid shrimp there is however the one consistency which is the absence in all stages of exopods on the fourth and fifth pereiopods (Butler 1980). Larvae, once they settle out of the water column, metamorphose into juveniles. Juveniles may occupy different habitat than the adult animals (generally shallower water). The adult phase of all the species of Pandalid shrimp in B.C. waters is unique in that these animals are among the few animals in the world that exhibit protandrous hermaphrodism. This is a condition where an individual spends the early part of its life as a functional male (ages 1 and 2) and the later part (age 3 and rarely age 4) as a female. The female shrimp become egg-bearing in the fall or early winter and carry their fertilized eggs on their swimming legs (pleopods) until they hatch in the spring (see Fig. 1). Some species have the ability to skip the male phase and mature directly as females. This later condition may be a mechanism for a population to remain resilient. Charnov (1982) discusses the adaptive advantages for an animal to become primary female. This condition seems to arise when there is an imbalance between the number of males and the number of females, which can occur when a strong year class is present or when the older year classes have been overfished.

Reproduction of Pandalid shrimp

Decapods transmit sperm via spermatophores, which in most species, are delivered to the female by the anterior two pairs of copulatory swimming legs (pleopods) of the male. The sperm duct, which is glandular for spermatophore production, ends in a musculature ejaculatory duct, which opens near the coxae of the last pair of walking legs (pereiopods). In the female the oviducts open at gonopores near the coxae of the third pair of pereiopods. In the case of protandrous hermaphroditic species, traces of both pairs of openings are evident in both sexual phases.

The eggs are fertilised at the time of release (the timing of this varies by region and species) as they pass over the spermatophores. The eggs are then attached to setae on the pleopods. These setae appear to be developed as part of the breeding dress moult of the females. Eggs are carried on the pleopods until they hatch in the spring and produce larvae, which are released into the water column.

Age and Growth of Pandalid shrimp

Growth is a discontinuous process and is associated with moulting of the exoskeleton. The number of moults that an animal goes through in a year varies by age and life stage. The pattern of growth however remains fairly consistent between species of Pandalid shrimp. Starting with the larval period, the number of zoeal stages that an animal goes through before it settles out as a juvenile can vary from 5 to 12 depending on the species. The length of time that it takes to go through these various instars will depend on the environmental factors such as temperature but it is generally thought to be 2-3 months. Growth seems very rapid in the spring/summer and slows down in the late summer fall with the onset of gametogenesis. The females once they are egg bearing will stop moulting while the males will resume growing after the fall/winter-spawning season.

The age of these animals is determined through an analysis of length frequencies. The reported ages for some of these species varies considerably between areas within their ranges. There is some controversy as to the ageing methods and sampling procedures used in age determination. Problems with ageing can arise for a number of reasons. Care must be taken not to add age groups to an analysis by lumping samples from different areas because substantial variations in growth rates can occur between areas in rather close proximity. It is also important to keep track of the life stage of the animal; the transitional instars will generally form a mode between male and female stages of the same year class. To keep track of the variations of growth within a single year class it is necessary to analyse samples from throughout a year. In the spring, incorrect interpretation of length frequency samples can occur if the samples do not distinguish between the previous years egg-bearing females and the present year's primiparous (first time producing eggs) females.

Trophic Relationships of Pandalid shrimp

Shrimp are generally opportunistic foragers, i.e. scavengers, although there are behavioural nocturnal migrations that indicate that they are also active foragers. Active predation occurs on such animals as copepods, amphipods, euphausiids, mysiids, polychetes, etc. Depending on their life stage and size, they are prey to many other invertebrates such as octopus and crabs as well as fish such as hake, rockfish, dogfish, pollock and cod. There are indications that populations of some shrimp species respond to the presence or absence of predators such as gaddid fishes (Anderson in press).

Pandalid shrimp occupy a number of different niches and habitats and may be the dominant organism within that area. Some species are exclusively benthic, some are primarily benthic but show nocturnal pelagic migrations and some are predominantly pelagic in nature. They also occupy different habitats from rocky, sandy to green mud. They are found at depths ranging from intertidal tide pools to 1300+ m.

Parasites and Diseases of Pandalid shrimp

There are a relatively few known parasites and diseases that affect Pandalid shrimp in British Columbia, they include:

- Parasitic isopods : *Bopyroides hippolytes*
- Rhizocephala: *Sylon hippolytes* (Bower and Boutillier 1990)

- Protozoan microsporidia: *Thelohania sp.*
- *Rickettsia* like micro-organism (stained prawn disease) (Bower et al 1996)
- *Hematodinium* like organism (has yet to be identified)
- Viral infections (only found in prawn aquaculture situations to date)

Population structure and Dynamics of Pandalid shrimp

The populations may be part of large metapopulations spread over vast offshore regions or small isolated populations in inshore inlets. Because of the diversity of habitat niches that Pandalid shrimp populations in British Columbia occupy, the abiotic and biotic processes that control these populations vary considerably. Highly fluctuating populations of shrimp are found in offshore areas where currents are susceptible to large scale physical forcing factors like El Nino. Relatively stable populations are found in isolated inshore areas where currents are more tidally driven and more consistent from year to year. The offshore shrimp populations have more complex stock recruitment relationships with a large environmental component while the inshore populations would have strong direct stock recruitment relationships. These two scenarios make the risks of managing exploitation of shrimp stocks in the offshore regions quite different from the inshore regions. In the offshore region the risk is how to optimise the harvest when environmental conditions can cause the population to collapse in the absence of a fishery as opposed to the inshore regions where the stock are vulnerable to recruitment overfishing.

Pandalid shrimp populations have a number of interesting adaptive mechanisms that affect their ability to respond (resilience) to perturbations such as fishing. Compensatory adaptive mechanisms include variations in growth rates, onset of primary females, variations in natural mortality, and possibly variations in reproductive output. This can lead to situations where a fishery, which once exploited three year classes, is almost totally dependent on new year recruits.

Life history table for Pandalus hypsinotus

Common names: Humpback shrimp, Coonstripe, King shrimp, Helmet shrimp (Korea)
Maximum size: Butler (1980) reports 39.6 mm carapace length for British Columbia, while Kurata (1981) reports females up to 50.0 mm carapace length from the Sea of Japan.
Life History: Butler (1980) describes the life history of this species for southern B.C. waters. Larvae hatch in late March or April and metamorphosis occurs in shallow waters (37-82m). Shrimp mature as males and in varying proportions as primary females at about 18 months. Males go through a transition phase at 23-25 months and then function as mature females. Females become egg bearing (berried) in late November early December and remain that way until the eggs hatch in the spring. He felt that survival into the fourth year was very low. Kurata (1981) describes variations of life history depending on the location and depth of populations off Japan. In the Japan Sea populations found that the shrimp live for four years and there was little indication of primary females in the populations. Most females are made up of newly recruited 3-year-old individuals and become egg bearing in the summer/fall with hatching occurring in

February/April. In deep-water populations off the Pacific coast he found a large number of non-ovigerous females throughout the year. There were also females with mature ovaries while still carrying external eggs. Buyanovsky (in press) feels that a majority of humpback shrimp from Tartar Straits live for up to five years.

Larval stages: Kurata (1981) noted that the number of larval stages and their rate of development depend upon the temperature that the shrimp are raised. At temperatures of 9^0 C or lower, post-larva develop after 5 zoeal stages, while an additional sixth zoeal stage is required when the animals are raised at temperatures in excess of 15^0 C even though larval development was completed significantly earlier at higher temperatures. Haynes (1976) reared six zoeal stages in Kachemak Bay, AK. Kurata (1981) cites that the optimal temperature for larval development through to post-larval settlement was in the range of 9^0C to 12^0C.

Habitat: Berkeley (1930) felt that metamorphosis to a juvenile stage occurs in relatively shallow water. There is then a migration out into deeper adult habitats. The post-zoeal stages are benthic and occupy rocky and mud type habitats.

Trophic Relationships: Butler (1980) and Kurata (1981) indicate that the diet of this species includes mysids, amphipods, other crustaceans, polychetes, annelids, bivalves, gastropods, ophiuroids and occasionally scales and bones of fish.

Parasites and Diseases: From biological samples obtained over the years the only parasites that have been found in *Pandalus hypsinotus* are branchial isopods and protozoan microsporidia.

Population structure and Dynamics: *P. hypsinotus* in B.C. waters is basically an inshore and shallow water species. The isolation of these unique populations would indicate the potential for strong stock/recruitment processes and would make these populations less susceptible to advection or influx of recruitment from other populations i.e. few metapopulation effects. Although there has been directed fisheries in B.C. (Fig. 2) and abroad, there is little information that is available from which to base an informed decision on the resilience of this species and the compensatory mechanisms that population may elicit under various exploitation rates. Most of the data to date shows a one way trip with the fishery causing a continuous decline in population indices with no sign of recovery. From the catch logs from commercial trap and trawl shrimp fisheries, we do know that the species does coexist as a sub-dominant species in many areas of the coast especially with the B.C. prawn, *Pandalus platyceros*. This incidental catch accounts for the small catches from 1987-1994 (Fig. 2). It is known to be the dominant shrimp species in a number of isolated areas that are usually shallower inlets and bays which account for some of the large increases in catches since 1995 (Fig. 2).

Fisheries for Pandalus hypsinotus

Japan

The Japanese fishery as describe by Kurata (1981) showed significant declines due to overfishing because the management actions imposed on the fishery were for social and economic reasons and the regulations did not protect the stocks from overfishing. Restriction focused on fishing activities such as restricting the area and time that otter trawls could be used (no inshore use), the size of beam trawls and the number of traps.

U.S.A. – Alaska

There was a fairly strong trap and trawl fishery in the Cook Inlet but the fishery closed in 1987 and has never reopened (C.Trowbridge Pers. Comm.). Managers in the area felt that the low abundance of this species was caused by a combination of fishing and environment factors. It was indicated that fishing may have driven the population so low that when negative changes in the environmental conditions occurred they caused the populations to enter a predator pit from which they could not recover.

Canada – British Columbia

This shrimp species is usually caught incidentally in the prawn trap and shrimp trawl fisheries in British Columbia although there has been a directed trap fishery for this species in Prince Rupert Harbour and Masset Inlet. The total landings for both fisheries combined have reached a high in excess of 90 tonnes in 1998 (Fig. 2). The Minister of Fisheries and Oceans put restrictions on expansion of the fishery in 1998 although a number of new directed trap and trawl fisheries were developed for humpback shrimp in 1999.

At present the directed trap fisheries for humpback shrimp are not managed and the fishery dependent CPUE indices of abundance are showing declining trends in abundance. For example, Figure 3 shows that the average annual CPUE of Humpback shrimp per trap haul in the Prince Rupert Harbour fishery in the last four years has remanded consistently below the 15 year average.

In the trawl fishery for humpback shrimp in Area 12, the fishery dependent and fishery independent indices of abundance (Table 2) both indicate severely declining trends in abundance.

Year	CPUE (kg/min towed)	Survey Biomass(t)
1997	0.26	30
1998	0.12	11.3
1999	0.02	2.8

Table 2: CPUE from trawl fishery and survey biomass indices for humpbacks in PFMA 12.

Data availability and quality

No information is available from first nations and recreational fishers although directed fisheries occur in Masset and Prince Rupert areas. The commercial shrimp trap and trawl fishery provides fishery dependant information although there were some earlier problems with reporting of the correct species in the north coast where the catch was reported under the common name Coonstripe shrimp rather than Humpback shrimp. Coonstripe shrimp is the common name used for *Pandalus danae.*

Additional information is available for select areas in which fishery independent area swept trawl and trap surveys are completed as part of the shrimp trawl fishery assessment program. Fishery independent data are also available from the shrimp trap fishery as part of the exploratory and experimental management surveys.

Trap fishery

Since 1984 the shrimp trap fishery has reported average landings of 20 tonnes per year of humpback shrimp. The range in catches has been from a low of 5 tonnes in 1986 to a high of 83 tonnes in 1998 (Fig. 2). The shrimp trap fishery logbook records from 1984-1999 show small landings of humpback shrimp from almost all the inshore statistical areas of the coast that are exploited in the prawn fishery with the exception of the south-westerly portions of Vancouver Island. The largest catches in the trap fishery are taken from the northern Pacific Fisheries Management Areas (PFMA) 1-8 with peak total annual catches by area (combined Coonstripe and Humpback Shrimp) over that time frame (1984-1999) ranging from one tonne in area 1 to sixty-nine tonnes in area 4. The next most productive area is the Central PFMA 9-12 with the total catches ranging from two tonnes in area 10 to eighteen tonnes in area 12. The Southern PFMA 13-19 including 28 and 29 catches ranged from <one tonne in Area 29 to four tonnes in Area 28. All areas along the west coast of Vancouver Island, PFMA 20-27, have reported landings of less then 100 kg with the exception of Area 27 which has had landings of up to three tonnes.

A summary of the number of PFMA areas and sub-areas with humpback trap fishery catches in excess of 1 tonnes is shown in Table 3 below.

Areas with trap catches >1 tonne in any single year	# of Sub-areas targeting humpbacks Catches >1 tonne in any year	# of Sub-areas with incidental catches <1 tonne.	Comments
1	1		Small directed fishery
2	1	16	Potential targeting in 3 other sub-areas. Overlap with the trawl fishery in 8 sub-areas. Targeted fishery started in 1999
3	2	14	Potential directed catch in 2 other sub-areas
4	4	4	Overlap with trawl fishery in 2 sub-areas of the potential targeted fishery. The directed fisheries in this area have not been managed and are presently showing fishery dependant abundance indices well below historical averages (Fig.1)

5	1	14	Some potential overlap with trawl fishery in the region
6	2	24	Potential conflict with trawl fishery but minimal at this time
7	0	25	Exploratory surveys have found isolated populations in the area but they do not appear to be targeted at this time.
8	3	11	No conflict with the trawl fishery to date
12	2	26	Overlap with trawl fishery in the region in both targeted and non-targeted areas
13	1	14	Isolated from the trawl fishery in this area
28	1	4	Potential conflict with trawl fishery, however the trawl fishery is now closed in this area

Table 3: A summary of those PFMAs reporting in excess of 1 tonne of humpback shrimp landed in the shrimp trap fishery in a single year from 1984-1999. The summary includes the number of sub-areas reporting landings and those sub-areas where the fishery could be potentially targeting on humpback shrimp.

Trawl fishery

The trawl records from 1987 to 1999 shows that the trawl fishery has on average landed 10 tonnes of humpback shrimp a year. The catches range from a low of 1 tonne in 1994 to 60 tonnes in 1996 (Fig.2). The major landings in the trawl fishery are in PFMA 12. Biomass surveys of the fisheries in this PFMA indicate that for some fisheries, humpback shrimp make up 25-30% of the total shrimp biomass.

A summary of the PFMA areas and sub-areas with humpback shrimp catches in excess of 1 tonne in any year are shown for the shrimp trawl fishery in Table 4 below.

Areas with trawl catches >1 tonne in any single year	# of Sub-areas targeting humpbacks Catches >1 tonne in any year	# of Sub-areas with incidental catches <1 tonne.	Comments
2	1	4	Fishery expanded in 1999.
4	2	6	Some overlap with the trap fishery potential conflict
5		6	See comments in trap summary
7		8	See comments in trap summary

12	3	6	All three targeted areas have shown drastic reductions in CPUE and in survey biomass indices (Fig 2)
13	1	4	See comments in trap summary
14	1	12	Does not appear to conflict with any trap fishery for this species. The main target area is presently closed to trawling due to high incidental catches of prawns
18	3	5	Main catch areas are target fisheries for *P. danae*.
19	1	0	Main catch area is a target fishery for *P. danae*

Table 4: A summary of those PFMAs reporting in excess of 1 tonne of humpback shrimp landed in the shrimp trawl fishery in a single year from 1984-1999. The summary includes the number of sub-areas reporting landings and those sub-areas where the fishery could be potentially targeting on humpback shrimp.

Discussion

Management of recruitment overfishing in shrimp fisheries

Recruitment overfishing is managed in shrimp fisheries in British Columbia with either a fixed exploitation rate or a fixed escapement target (Boutillier et al. 1996, Boutillier and Bond 1999).

The shrimp trawl fishery started to be managed using a fixed exploitation rate in 1997. Prior to that time there was no management of recruitment overfishing for this fishery. A fixed exploitation rate of 33% is applied to inseason biomass estimates of twelve index fisheries spread over the coast. Where appropriate, the index area biomass indices are then extrapolated to other areas using weightings from fishery dependent CPUE and total area estimates. Areas used in these comparisons must have similar species composition and age class proportions as the index areas.

The prawn trap fishery has been managed using an index of female spawner since 1979. This management system was developed based on empirical data collected from a series of assessment cruises carried out in the early to mid-1970's in Knight and Kingcome Inlets (Boutillier 1988, 1993, Boutillier and Bond 1999). The escapement index is monitored using inseason at-sea sampling of the commercial catch per trap of the female cohort.

Assessing and managing recruitment overfishing in a Humpback shrimp fishery

Developing a fixed escapement management system for humpback shrimp will be complicated because of the biology of the animal. For prawns, which are a semelparous animal, it is relatively easy to estimate a fixed escapement index by assessing the number of females in the catch throughout the year. It becomes much more complicated for humpback shrimp, because of their ability to skip the male phase to become a primary female and also being capable of producing more than one batch of eggs (being multiparous). Primary, one-year-old, females are not likely to be as fecund as the larger older two-year-old females therefore basing a spawner index on counts of females alone, as is done with prawns, would not be appropriate. A more complex escapement index based on egg production would have to be developed. This escapement index would have to incorporate size of the animals, number of animals at each size, and the fecundity at size. The second problem is that unlike the prawn fishery, which is basically a trap only fishery on which we base the CPUE index, it will be complicated to establish meaningful and comparable trap/trawl indices if both methods of fishing are employed. The final problem is that unlike the prawn trap fishery which had a history of stable fishing and empirical survey data on which to base the spawner index, the humpback fishery does not have this historical data set from which to base even a preliminary escapement index.

Developing a management system that is based on a fixed exploitation rate requires information on the total stock size of the animals. For the shrimp trawl fishery, we are presently developing a survey methodology that combines an area-swept trawl density estimate with a trap survey that compares the relative density of animals in trawlable and untrawlable areas. Other estimation procedures are available which include: reconstruction of historical catch, effort, age and size data, mark recapture and change in ratio methods and depletion estimates (Hilborn and Walters 1992). Boutillier and Bond (1999) outlined the pros and cons associated with each one of these methods as it applies to the prawn trap fishery. One of the major problems that will be facing the humpback fishery is that there is probably a minimum of two dozen small distinct humpback populations that could be targeted and would require direct assessment. Developing biomass estimates for this number of fisheries is very expensive and keeping track of the catch from each small area will require some type of validation system. Identification of the humpback areas is possible from the trawl fishery logs because of the requirement to keep track of the catch by latitude and longitude. Unfortunately the identification of the humpback area in the trap fishery can not be done as precisely because the industry only reports catches by sub-area.

Managing growth overfishing in shrimp fisheries

Growth overfishing is managed in the trap fishery for prawns using minimum size limit and size selective trap escapement mechanisms (Boutillier 1984, 1985). The trap industry recognises the benefits accrued by the size limit for prawns and have asked that the size limit be increased to take advantage of the higher prices paid for larger prawns (Morrison et al. 1998).

There is no growth overfishing management controls in the shrimp trawl fishery. The trawl industry repeatedly complains about the small shrimp in the spring and there have been repeated recommendations (Boutillier 1988, 1993) to take advantage of the rapid growth rates in the spring. Development of size selective gear modifications is being experimented with in the industry but at this time there is no management of growth overfishing in the trawl fishery.

Assessing and managing growth overfishing in the humpback shrimp fishery

The appropriateness of managing for growth overfishing would have to be determined through an economic and biological yield per recruit modelling exercise. This type of analysis will require not only information on the growth and mortality of the shrimp but also an understanding of the ex-vessel prices for humpbacks and how that might vary by size and product type.

Processors indicate that for trawl caught humpbacks the small humpbacks were being machine peeled with the pink shrimp and receiving \$0.50 per pound while larger humpbacks were going for hand-peeling and getting \$0.85 per pound. Dock sales of fresh and live humpbacks in the trap and trawl fishery receive \$4 to \$5 per pound. Graded frozen product from the trap fishery receives \$2.50 - \$3 per pound for small and \$3-\$4 per pound for medium size humpbacks.

Variations in growth rates may require area specific information to optimize a yield per recruit model. A coast-wide size limit might be established but this may run into some of the same problems experienced in the prawn fishery where optimal size limits vary considerably between areas (Boutillier 1985).

Setting and implementing a size limit on shrimp in the trap fishery would be a fairly simple matter considering the history and technology that the prawn trap industry is presently employing. If the optimum size range varies from the prawn industry and the escapement modifications were reduced for the humpback shrimp trap, this would lead to a complicated enforcement plan for trap mesh restrictions in the shrimp trap fishery for two species which often co-habitat.

Implementation of a size limit in the trawl fishery would be much more difficult. At present there is no proven technology presently employed although the industry is experimenting on some selective fishing methodologies for implementation in the sidestripe fishery.

Other assessment and management issues

Effort

Development of a directed fishery specifically for humpback shrimp which is available to 500+ vessels that are presently allowed to operate in the shrimp trawl and trap fishery could be unmanageable. In most areas of the coast, humpback shrimp will probably remain a by-catch in the trap and trawl fisheries, however, in the two dozen or so areas that would support a directed humpback fishery, effort control should be considered.

Bycatch

Bycatch is a problem in both the trap and the trawl fishery. In the trap fishery the major bycatch is restrict to those animals that can enter small tunnels and not escape the large mesh. Animals brought up in a trap are generally in good shape and can usually be returned alive if released immediately, as is evident from prawn tagging studies.

The diversity of animals brought up in a trawl is very much greater than the diversity of animals brought up in traps. Bycatch in the trawl fishery is being addressed through the use of grates and soft panels (industry has recommended mandatory requirements for these in all trawls in the 2000-fishing plan). These grates and panels have allowed sorting of the catch while the trawl is on the bottom, although there is no information on the survival rate of the animals that are released. The grates seem to be very effective on the elimination of larger fish but their effectiveness in eliminating small fish seems to be a function of the type of trawl used. Otter trawls, which are towed at greater speeds, have significantly higher catch rates of small fish than do beam trawls.

Allocation

Allocation of the humpback shrimp fishery between the trap and trawl industries will be complicated in the fact that all areas can be fished with traps but not all the areas can be trawled. There is a potential for gear conflicts in some areas.

Collateral damage

Both long-lined traps and trawls are capable of causing collateral damage to the habitat especially sessile habitat forming organisms such as sponges and corals. The impact of course will vary by the area and the species, as the fishery grows they will be fishing in more and more areas that have not previously been exploited or surveyed.

Conclusions

There appear to be a number of areas that could support a directed fishery for humpback shrimp. If a directed fishery develops then the following items should be addressed in an assessment framework:

1. Identification and designation of exclusive humpback shrimp fishing areas.
2. Development of a precautionary management system that addresses recruitment overfishing and which incorporates clear decision rules e.g. Target Reference Points and Limit Reference Points and their associated management action level.
3. Development and testing of methodologies for abundance measurement indices.

4. Identification of abiotic, biotic and fishery information requirements to assess the efficacy of the precautionary management approach.
5. Development of experimental protocols to allow testing of the assumptions associated with the precautionary management system.
6. Development of models to address growth overfishing concerns.
7. Development of protocols to allow for environmental impacts assessment of the fishing operations by gear type and area (this will include bycatch mortalities and collateral habitat damage).

Recommendations

1. Remove the two dozen plus areas from the present trap and trawl fishery and designate them under a Humpback shrimp fishing plan. Some of this information can be garnered from the logbook records (especially the trawl logs) but both the trawl and trap industry should be canvassed to determine the priority areas for this fishery to develop. It will have to be determined how expansion into new areas should be restrictedd
2. The lack of specific fishing location information from the prawn logs is making it difficult to address a number of departmental objectives e.g. habitat referrals, treaty negotiations, etc. The condition of licence and logbooks should be changed to reflect the need for this information.
3. As was pointed out by Boutillier and Bond (1999) maximum production and lowest cost would be achieved through a fixed escapement policy. This however will not be possible in the short term, as there is no empirical information to base target or limit reference points. The fishery will have to initially be developed using a fixed exploitation rate, however, in the long term data should be collected to determine the appropriateness of fixed escapement targets as this method of management is cheaper to implement and generally produces higher catches. As mentioned previously, populations of humpbacks that are managed under the shrimp trawl exploitation rate of 33%, are showing severe declines. Precautionary target limit points for exploitation rates should be reduced to the 15-20% range until we understand the dynamics of the stocks better. The limit reference point for population levels should not allow the population to fall below maximum productivity, which is usually considered to be 25-50% of the virgin biomass. Natural variations of an unfished population would provide estimates of risks associated with the limit reference point.
4. Abiotic information should be collected in the area of the humpback shrimp populations, to determine how much of the variance in biological parameters such as recruitment, natural mortality etc. can be explained by environmental conditions. Unfortunately we do not have the capability to collect temperature, salinity and current information on an ongoing bases. Biotic information that will be necessary will be indices of abundance of various year classes and as well as condition indices which would at a minimum include sex, size, diseases, and fecundity. Fisheries specific information would be required to determine the cohorts and sizes of animals targeted by each gear type.
5. The quickest way of getting the information is through a series of experimental management approaches such as developed for the sea cucumber fishery (Boutillier et al 1996). This

would require fishing areas at various exploitation rates e.g. 0%, 15%, 30%, 45% and monitoring the compensatory and depensatory mechanisms that the populations experience at these various levels of exploitation. It may be possible to use populations in places like Gwaii Hanaas National Park as controls (0% exploitation) or develop MPA's in specific areas for this purpose.

6. Yield per recruit modelling will require extensive information about the impacts of the various fishing technologies employed and the market value of various products. Landing validations of quotas is probably the best way of insuring that the economic information is obtained.
7. Protocols for environmental impacts will have to be developed as part of the selective fishing criteria. It may be that different areas have different sensitivities and would require different fishing standards. The habitat PSARC subcommittee should discuss an environmental assessment framework for this fishery in the designated areas.

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Figures

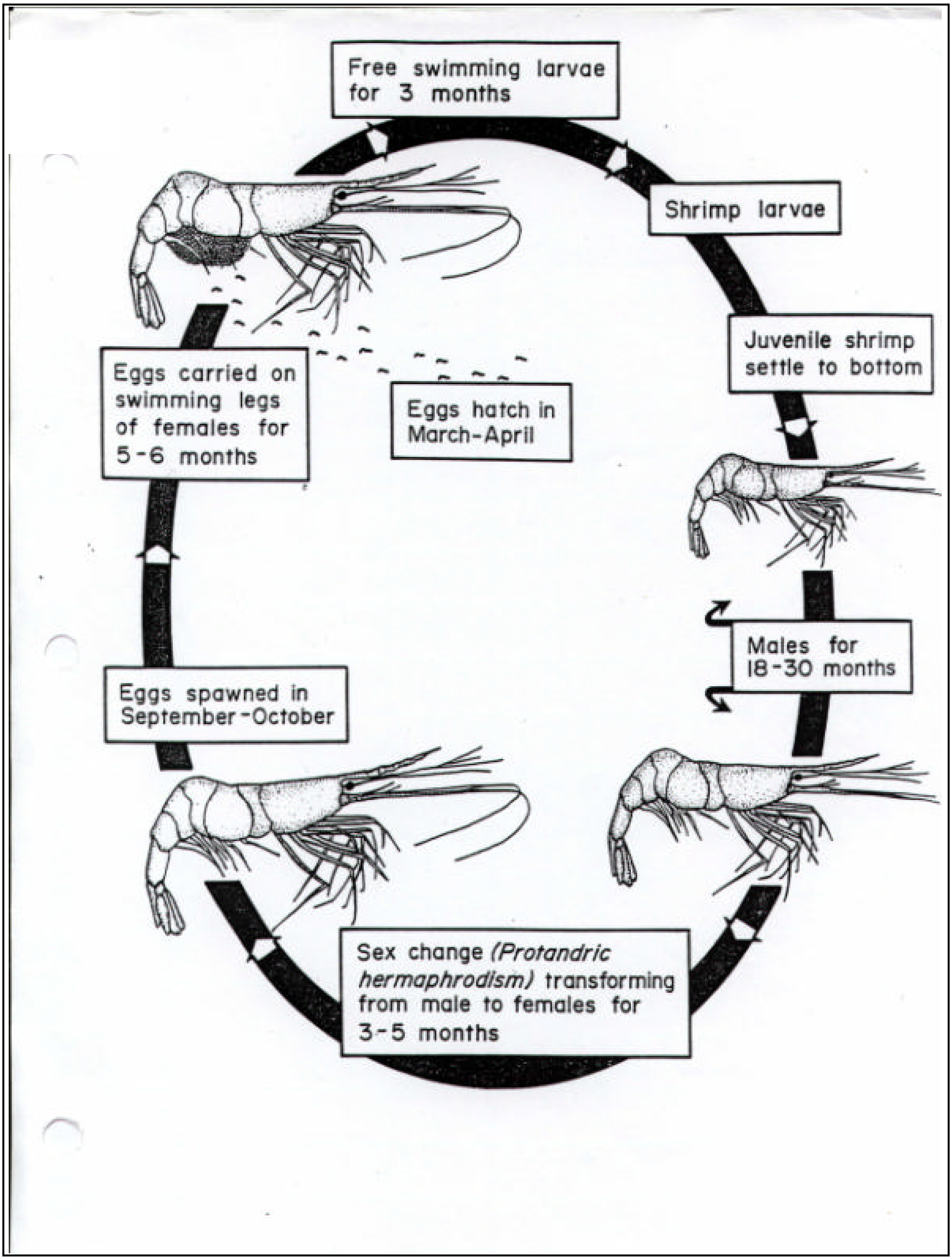

Figure 1: Generalized life history

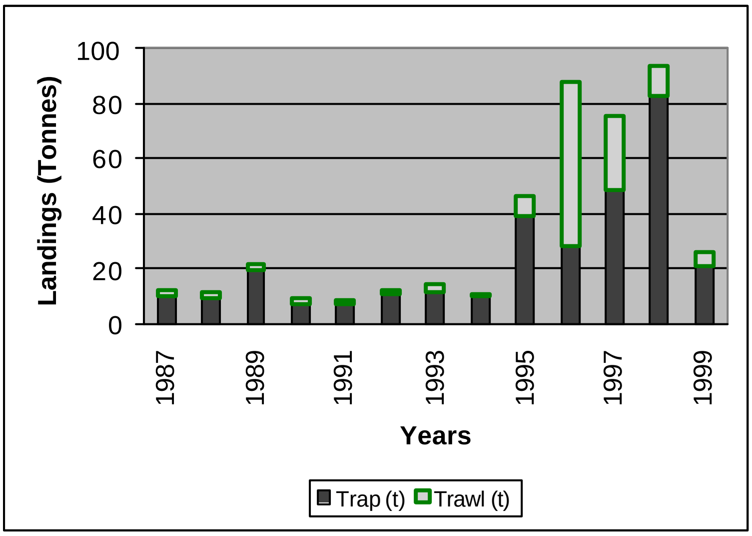

Figure 2: Total landings of humpback shrimp by trap and trawl fisheries.

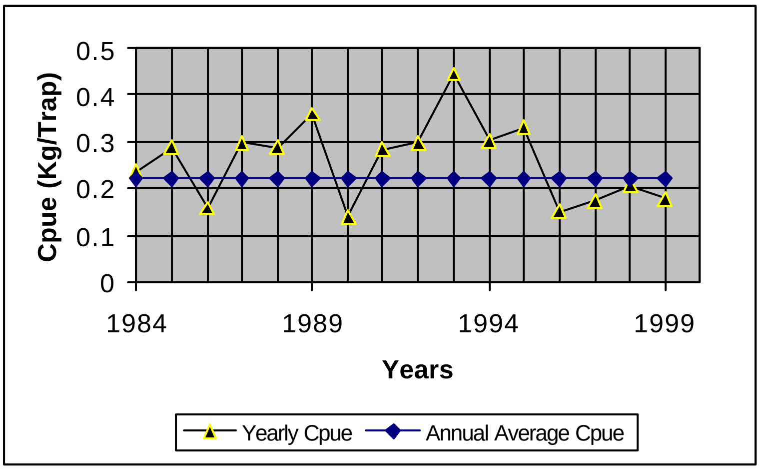

Figure 3: Yearly average CPUE and the Historical Average of all the Annual CPUEs of the humpback shrimp trap fishery in PFMA 4-10 and 4-11 combined.