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Pandalus danae, Coonstripe shrimp:

A Review of the Biology and Recommended Assessment Framework for Directed Fisheries

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Abstract

In response to Fisheries and Oceans Canada's New Emerging Fisheries Policy, the Pacific Region has developed an implementation framework for emerging fisheries. This paper was produced to meet the stage 1 "information stage" requirements of this framework and presents an appropriate assessment and management framework for the development of directed fisheries for coonstripe shrimp (*Pandalus danae*) in British Columbia.

Important aspects of coonstripe shrimp biology that the assessment framework addresses include: 1) the possibility of limited larval dispersal; 2) the phenomenon called protandrous hermaphrodism; 3) the ability to produce primary females; and 4) the potential multiparous nature of the shrimp.

In Alaska, Washington, Oregon and California coonstripe shrimp are incidentally exploited in shrimp trap and trawl fisheries. In Washington, there are also directed trap and trawl fisheries for coonstripe shrimp. In California, there are commercial and recreational trap fisheries. In British Columbia, coonstripe shrimp are incidentally exploited by recreational and aboriginal fishers who generally target prawns, although coonstripe shrimp are targeted by sport fishers around Sidney and Sooke (Pacific Fisheries Management Areas 19 and 20). Coonstripe shrimp are exploited by commercial trap and trawl fisheries, generally as bycatch to other targeted shrimp species. A directed trap fishery has existed in Areas 19 and 28, a fishery continues today in Area 20. The trawl fishery began targeting coonstripe shrimp in Areas 18 and 19 around 1995.

Regulatory approaches for controlling recruitment and growth overfishing are described for coonstripe shrimp fisheries in British Columbia. In Areas 18 and 19, the commercial trawl fishery is managed using fishery independent stock assessment trawl and trap surveys (to estimate stock sizes), exploitation rates and quotas. The current survey methodology and quota system were developed for mixed shrimp stocks and are not appropriate for a directed coonstripe shrimp trawl fishery. Problems with the current methodology include: 1) large variations in biomass estimates, and 2) surveys are not being done at the particular sites where coonstripe shrimp are targeted. Coonstripe shrimp stocks in Areas 18 and 19 should be identified and surveyed separately from other mixed shrimp stocks. The quota system should be revised to: 1) apply specifically to coonstripe shrimp stocks to ensure that the season for exploiting these shrimp does not close when the quota for another shrimp species is reached; and 2) target the larger size classes, not the entire population, because larger animals are being targeted by fishers. A catch validation monitoring program should be implemented to measure the fishery impacts which result from removing the larger shrimp size classes. A fixed escapement management system cannot be used at this time to manage coonstripe shrimp fisheries due to the complex biology of the shrimp and lack of data. Size limits are not currently used in coonstripe shrimp trap and trawl fisheries. It would be simple to implement a minimum size limit in the trap fishery, but more complicated for a trawl fishery. Fishing effort should be controlled in a trawl fishery for coonstripe shrimp; effort is already controlled in the trap fishery in Area 20 through restrictions on trap numbers and short openings. No reserves have been established to protect coonstripe shrimp stocks from exploitation. Bycatch and collateral damage are serious issues in the trap and trawl industries and should be quantified through a bycatch monitoring program. Allocation between trap and trawl gear will be an issue in directed fisheries because trap and trawl areas overlap. More management flexibility would be available if directed coonstripe shrimp fisheries were included under the Pacific framework for emerging fisheries. Much of the research that has been done on coonstripe shrimp occurred 70 years ago at locales other than in Areas 18, 19 and 20; additional biotic and abiotic information about coonstripe shrimp is needed in these three areas. The paper concludes that there is potential for targeted coonstripe shrimp fisheries within BC's coastal waters, especially in Areas 18, 19 and 20, under a precautionary framework.

Résumé

En réponse au document *Politique : Les nouvelles pêches* de Pêches et Océans Canada, la Région du Pacifique a préparé un cadre de mise en oeuvre pour les nouvelles pêches. Le présent rapport répond aux exigences de la phase I du cadre, soit la phase de la cueillette de renseignements, et établit un cadre d'évaluation et de gestion approprié pour le développement de pêches dirigées de la crevette des quais (*Pandalus danae*) en Colombie-Britannique.

Les aspects importants de la biologie de la crevette des quais couverts dans le cadre d'évaluation incluent les suivants : 1) la possibilité d'une dispersion limitée des larves; 2) le phénomène de l'hermaphrodisme protérandrique; 3) la capacité de produire des femelles de premier ordre; et 4) la nature multipare potentielle de l'espèce.

Dans les États de l'Alaska, de Washington, de l'Oregon et de Californie, la crevette des quais est incidemment capturée dans le cadre de la pêche crevettière au casier et au chalut. Elle est aussi l'objet de pêches dirigées au casier et au chalut dans les eaux de l'État de Washington et de pêches commerciales et sportives au casier en Californie. En Colombie-Britannique, elle est incidemment capturée par les pêcheurs sportifs et autochtones qui ciblent généralement la crevette tachetée, bien qu'elle soit recherchée par les pêcheurs sportifs aux environs de Sidney et de Sooke (secteurs d'exploitation des pêcheries du Pacifique 19 et 20). Elle est aussi capturée au casier et au chalut par les pêcheurs commerciaux, généralement à titre de prises accidentelles dans le cadre de pêches ciblant d'autres crevettes. Une pêche dirigée au casier a déjà eu lieu dans les secteurs 19 et 28, pêche qui se poursuit encore dans le secteur 20. Les chalutiers ont commencé à cibler la crevette des quais dans les secteurs 18 et 19 vers 1995.

Suit une description des mesures réglementaires visant à refréner la surpêche en Colombie-Britannique du potentiel de croissance et de reproduction de la crevette des quais. Dans les secteurs 18 et 19, des relevés indépendants des stocks au chalut et au casier (pour en estimer la taille), des taux de prise et des quotas sont utilisés pour gérer la pêche commerciale au chalut. Mais les méthodes de relevé et le régime de quotas utilisés, élaborés pour gérer les stocks de crevette mélangés, ne sont pas propres à la gestion d'une pêche dirigée de la crevette des quais au chalut. Les méthodes actuelles souffrent des carences suivantes : 1) de fortes variations des estimations de la biomasse et 2) les relevés ne couvrent pas les pêcheries actuelles de la crevette des quais. Les stocks de crevette des quais dans les secteurs 18 et 19 devraient être cernés, puis faire l'objet de relevés indépendants des stocks mélangés. Le régime de quotas devrait aussi être révisé de sorte à ce qu'il : 1) s'applique plus particulièrement aux stocks de crevette des quais afin d'assurer que la saison de pêche de cette crevette ne soit pas fermée lorsque le quota d'une autre espèce a été récolté et 2) cible les classes de grosses crevettes et non l'ensemble de la population car les pêcheurs ciblent les grosses crevettes. Un programme de vérification des prises devrait être mis en oeuvre en vue de mesurer les incidences de la pêche imputables au prélèvement des grosses crevettes. Un régime de gestion axé sur un niveau fixe d'échappement ne peut pas être utilisé à ce moment-ci pour gérer la pêche de la crevette des quais à cause de la complexité de la biologie de l'espèce et du manque de données. La pêche de la crevette des quais au casier et au chalut n'est pas assujettie à des limites de taille à l'heure actuelle. Il serait simple d'imposer une limite de taille minimum pour la pêche au casier, mais cela serait plus compliqué dans le cas de la pêche au chalut. L'effort de pêche de la crevette des quais au chalut devrait être limité, l'effort au casier dans le secteur 20 étant déjà limité par des restrictions sur le nombre de casiers et des ouvertures de la pêche de courte durée. Aucune réserve n'a été établie pour protéger les stocks de crevette des quais de l'exploitation. Les prises accessoires et les dommages indirects imputables à la pêche au casier et au chalut sont des problèmes graves et devraient être quantifiés à l'aide d'un programme de contrôle des prises accessoires. La division des quotas de pêche dirigée entre les caseyeurs et les chalutiers sera un problème parce que les secteurs de pêche au casier et au chalut se chevauchent. L'inclusion de la pêche dirigée de la crevette des quais dans le cadre pour les nouvelles pêches dans le Pacifique offrirait une plus grande latitude de gestion. La plus grande partie des recherches faites sur la crevette des quais datent de 70 ans et ont été effectuées à des endroits autres que les secteurs 18, 19 et 20. De nouvelles données biotiques et abiotiques sur la crevette des quais de ces trois secteurs sont requises. Les auteurs concluent que des pêches dirigées de la crevette des quais, assujetties à un cadre préconisant la prudence, pourraient être autorisées dans les eaux côtières de la Colombie-Britannique, en particulier dans les secteurs 18, 19 et 20.

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Introduction

In September 2001, Fisheries and Oceans Canada adopted the final version of the national policy on new and emerging fisheries. This national process incorporates principles that cover issues concerning conservation, the precautionary approach, ecological considerations, science needs, First Nations, transparency of process, accountability, and responsibility (Fisheries and Oceans Canada 2001a). In response to the document, the Pacific Region has developed an implementation framework for new and emerging fisheries that covers four stages: 1) information; 2) experimentation; 3) exploration; and 4) objective-based fishery management. This staged approach is adopted from an assessment framework that the Pacific Region Shellfish Stock Assessment Section utilises for provision of scientific advice for management of invertebrate fisheries (Perry et al. 1999).

This paper was produced to meet the requirements of the stage 1 "information stage" for directed coonstripe shrimp, *Pandalus danae,* fisheries. Coonstripe shrimp have been incidentally exploited in shrimp trap and trawl fisheries ever since these fisheries began in B.C.'s coastal waters. Coonstripe shrimp have also been targeted throughout the 1900s by the trap fishery in specific locations throughout southern BC waters. The trap fishery has proceeded for years with a variety of management regulations. Since 1995, there has been increased interest in trawling for coonstripe shrimp in southern areas, especially in Areas 18 and 19, as market demand for live coonstripe shrimp, particularly after the closure of the prawn fishery, is usually higher than for other shrimp. The trawl fishery presently exploits coonstripe shrimp as part of the quota system already in place for mixed shrimp stock fisheries.

The objectives of this paper are:
1) to review the biology of Pandalid shrimp and coonstripe shrimp;
2) to describe coonstripe shrimp fisheries and their respective management regimes throughout the Pacific northwest in the United States and Canada, focusing on B.C.'s trap and trawl fisheries;
3) to discuss recruitment overfishing, growth overfishing, and effort regulatory approaches. Other management issues including bycatch, collateral damage, allocation and cost, why directed coonstripe shrimp fisheries should be managed under the Pacific framework for emerging fisheries, and relevant coonstripe shrimp biological data that are required;
4) to provide recommendations regarding the establishment of directed coonstripe fisheries in British Columbia.

Shrimp Fisheries in British Columbia

There are in excess of 87 species of shrimp in British Columbia waters. Of these, there are seven commercial species of shrimp exploited by trap and trawl fisheries in B.C. All seven species belong to two genera in the family *Pandalidae.* Table 1 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.

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 oceans of the world. The family is divided into eighteen genera (Butler 1980, Ruppert and Barnes 1994). In British Columbia there are 12 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*
              - *P. borealis eous*
              - *P. danae*
              - *P. jordani*
              - *P. goniurus*
              - *P. hypsinotus*
              - *P. platyceros*
              - *P. stenolepsis*
              - *P. tridens*
            - *Genus Pandalopsis*
              - *P. dispar*
              - *P. lucidirimicola*
              - *P. ampla* *
              - *P. rubra* *

* Identification requires confirmation

Life History

In general, Pandalid shrimp start their lives as larvae that hatch in the spring (Fig. 1). The number of stages and the morphology of larvae vary considerably between species. The rate of development through these stages is affected by environmental conditions such as temperature, but generally larvae remain in the water column for two to three months. Although larvae differ considerably between the various species of Pandalid shrimp, there is one consistency which is the absence at all stages of exopods on the fourth and fifth pereiopods (Butler 1980). Larvae, once they settle out of the water column, metamorphose into juveniles that may occupy different habitat than the adult animals (generally shallower water).

The adult phase of all species of Pandalid shrimp in B.C. waters is unique; these shrimp 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 latter part (age 3 and rarely age 4) as a female. 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 (Fig. 1).

Some species have the ability to skip the male phase and mature directly as females which may be a mechanism for a population to remain resilient. Primary females increase the reproductive potential of a population by producing a new generation every year instead of every second or third year. Charnov (1982) discussed the adaptive advantages for an animal to become a primary female; they are a compensatory mechanism to protect populations from stress such as extreme environmental conditions. Primary females may be more prevalent in populations living at the extremes of their ranges or in shallower water. This condition seems to arise when there is an imbalance between the number of males and females, which can occur when a strong year class is present or when the older year classes have been overfished.

Reproduction

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.

Eggs are fertilised at the time of release (the timing of this varies by region and species) as they pass over the spermatophores. They are then attached to setae on the pleopods. 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

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 five to 12 depending on the species. The length of time that it takes to go through these various instars will depend on environmental factors such as temperature, but it is generally believed to be two to three months. Growth seems very rapid in the spring/summer and slows down in the late summer/fall with the onset of gametogenesis. Females, once they are egg-bearing, will stop moulting while males will resume growing after the fall/winter spawning season.

The age of shrimp is determined through an analyses of length frequencies. The method is described in Schnute and Fournier (1980). The reported ages for some 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 combining samples from different areas because substantial variations in growth rates can occur between areas in 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. In order to keep track of variations of growth within a single year class, it is necessary to analyse samples collected throughout the year. In the spring, incorrect interpretation of length frequency samples can occur if samples do not distinguish between the previous year’s egg-bearing females and the present year’s primiparous (first time producing eggs) females.

Trophic Relationships

Shrimp are generally opportunistic foragers (i.e., scavengers), although there are behavioural nocturnal migrations, indicating that they are also active foragers. Active predation occurs on such animals as copepods, amphipods, euphausiids, mysids, polychetes, etc. Depending on their life stage and size, shrimp are prey to many other invertebrates, such as octopi and crabs, as well as fish, such as hake, rockfish, dogfish, pollock and cod.

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 including rock, sand and green mud substrates. Pandalid shrimp are found at depths ranging from intertidal tide pools to greater than 1300 m.

Parasites and Diseases

The few known parasites and diseases that affect Pandalid shrimp in British Columbia 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

Shrimp populations may be part of large metapopulations spread over vast offshore regions or small isolated populations in inshore inlets. The abiotic and biotic processes that control these populations vary considerably because of the diversity of habitat niches that Pandalid shrimp populations occupy in British Columbia. 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 complex stock recruitment relationships affected by a large environmental component, whereas the inshore populations 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 offshore regions the risk is how to optimise exploitation when environmental conditions can cause populations to collapse in the absence of a fishery,as opposed to inshore regions where stocks 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 third year classes, is almost totally dependent on new year recruits.

Biology of Coonstripe shrimp, *P. danae*

Common Names

Coonstripe shrimp are called dock shrimp and, in California, prawns (Berkeley 1929c). Humpback shrimp, *Pandalus hypsinotus*, are sometimes called coonstripe shrimp. *Pandalus gurneyi* Stimpson, 1871 (Wicksten 1991) and *P. franciscorum* Kingsley, 1878 (Holthuis 1980) were synonyms given to *P. danae* specimens misidentified and believed to be separate species.

Description

Coonstripe shrimp have irregular striping on the abdomen (Butler 1964), there may be spots as well, and banding on the antennae and pereiopods (Wicksten 1991). Striping is especially evident in younger individuals (Berkeley 1930). There is variation in shrimps' color patterns (Wicksten 1991, Butler 1980). Generally, shrimp from Puget Sound and British Columbian waters have brown bands on the body and white or translucent bands on the appendages. In contrast, shrimp from southern Californian waters have red bands and a few blue spots on the body and yellow bands on the appendages. However, some larger individuals from southern Californian waters are translucent with brown stripes, similar to ones in Puget Sound waters (Wicksten 1991).

Coonstripe shrimp have 10-12 dorsal spines, about half of them on the carapace. The rostrum is a little longer than the carapace, the terminal half is unarmed, the lower margin has 6-8 spines (Berkeley 1930). For an identification key, refer to Butler (1980). For a method of rapid and easy identification, refer to Butler (1950).

Habitat

Coonstripe shrimp live in shallow bays and inlets. They are sublittoral; generally they are found on bottoms of course sand, gravel, stones or shell, usually where rapid tidal currents exist (Schmitt 1921, Butler 1964, 1980). Coonstripe shrimp are never found in mud (Berkeley 1926). In southern British Columbia, larger specimens are caught at depths between 18 and 64 m (Smith 1928; Berkeley 1929b, 1930). Small coonstripe shrimp (<5 cm total length) sometimes move into shallow water only a few meters deep (Smith 1928, Berkeley 1930), generally in late summer or autumn (Butler 1980), where they are observed on eelgrass (*Zostera* sp.) flats, rocky reefs, and around wharves and pilings (Wicksten 1991). Female coonstripe shrimp may leave the open sandy bottom and live amongst rocks (Berkeley 1930).

In British Columbia and Washington, coonstripe shrimp are found in low intertidal and shallow subtidal regions (Wicksten 1991). Temperature, depth and salinity in Indian Arm and Burrard Inlet, B.C. where *P. danae* was collected was 7.4-12.3ºC, 45-54 m and 25.2-30.1‰ respectively (Butler 1964). Off northern California, coonstripe shrimp are collected in water <92 m deep, generally at 38-55 m depth (Wicksten 1984). Temperature, depth and salinity in San Francisco Bay where *P. danae* was collected was ≤12.2ºC, 49-79 m and ≥25.7 ‰ (Schmitt 1921). Around Baja California coonstripe shrimp live subtidally among cracks and rocks in kelp beds and around breakwaters and on coarse sandy areas near reefs (Wicksten 1991).

Life History

Coonstripe shrimp sexes are separate. Mating takes place in October (Berkeley 1929b); males become sexually active (termed "active") (Butler 1980) and have the organs of copulation on the first pleopods and the enlarged appendices masculinae on the second pleopods (the latter are covered with heavy spines). In active males the vasa deferentia are packed with sperm. In females the ovaries are filled with blue-green eggs that can be observed through the clear integument (Berkeley 1931).

Female coonstripe shrimp moult before mating and oviposition occurs. At this moult, the pleopods develop long numerous setae to serve as supports for the eggs (Berkeley 1930, 1931). Recently moulted females probably secrete some substance to attract males, it being particularly strong in those that are ready to mate (Berkeley 1931). Females moult at night and eggs are laid about 36 hours after the moult (Berkeley 1929b, 1931). Mating can take place anytime during this 36 hours and will last between 15 and 60 seconds (Berkeley 1931). Ovigerous females occur throughout the year; however, the main season extends from November to April (Butler 1964, 1980). Females carry the eggs (about 1140 eggs, see Butler 1980) on the underside of the tail during the winter months (Berkeley 1929b, 1930). Coonstripe shrimp may lay more than one batch of eggs. Only a small proportion of females, compared to earlier stages, carry or hatch eggs (Berkeley 1930).

Coonstripe shrimp larvae hatch between the end of February and the end of May, with most larvae hatching in March and early April (Berkeley 1929b, 1930). Larvae generally hatch at night; the whole brood usually in one night, but sometimes two days or more are required (Berkeley 1930). There are five planktonic larval stages that last until late June (Butler 1964) and several post-larval stages where shrimps settle on the bottom and begin adult life (Berkeley 1930).

From the post-larval stages onwards, coonstripe shrimp display "protandrous hermaphrodism" (Berkeley 1929a). This is a condition where an individual spends the early part of its life as a male and the later part as a female. Most shrimps mature as males in October of the first year and become sexually active for the winter period (Berkeley 1930). Berkeley (1930) observed that many of these males remained as males the following winter, once again becoming sexually active in October. Butler (1964) observed that many individuals matured as females at 18 months, in the second autumn. Sex change of second-year males begins in the third spring as early as January and continues throughout the summer. In October, third year shrimp, now females, spawn for the first time (Berkeley 1929a, 1929b, 1930; Butler 1964, 1980). For a description about changes in the inner sex organs, please refer to Berkeley (1930).

The life of three-year-old coonstripe shrimp females after egg hatching in March and April is unclear (Butler 1964). Berkeley (1930) believes more than one year is spent as a female; thus, there may be a fourth-year group of larger females. After they lay their eggs, females may hide among rocks for the remainder of their lives. The life span of *P. danae* is three (Butler 1980), maybe four, years (Berkeley 1930).

Details mentioned above describe the life history of most coonstripe shrimp individuals. However, the following also occurs in populations. Some coonstripe shrimp hatch late in the spring and do not become sexually active males until the second autumn of their lives (Berkeley 1930). Some shrimp mature directly as females, never being males, and spawn within eight months of hatching. These shrimp are called primary females (Butler 1964, Marliave 1977).

Coonstripe shrimp larvae remain where they were hatched for at least three years in water about 46 m deep. Therefore, the majority of individuals in the first year are found together with those of the second and third years. There is a slight migration into shallow water (2 m deep) by very small adults, but the majority of specimens of this size are found with the mature forms in water 36-55 m deep. Four-year-old females, which may hide among rocks, might remain near the younger members because sandy shrimping grounds are usually surrounded by rock substrate (Berkeley 1930).

Larval Stages

There are five planktonic larval stages and several post-larval bottom forms. In March and April most larvae are in the first stage – by the middle of May most larvae are in the first two stages. One or two months are required for a larva to pass through the first two stages. At the beginning of June, most larvae are in the last four stages and by the end of June the majority have reached the sixth stage and have left the plankton (Berkeley 1930).

Larvae remain near the place of hatching (Butler 1964). Larvae in the first two stages are evenly distributed vertically in the water column (Berkeley 1930), not near the surface but between 18-55 m (Butler 1964). As later stages appear, they are found nearer and nearer the bottom (Berkeley 1930). Larval development stages as described by Berkeley (1930) are detailed in Table 2. Berkeley (1930) also provides detailed descriptions of external anatomy and larval stages.

Size and Growth

<u>Maximum Size</u>: male 26 mm carapace length (CL), male 123 mm total length (TL). Female 29 mm CL, female 140 mm (Butler 1980), 145 mm (Berkeley 1930) or 220 mm (Berkeley 1926) TL.

Coonstripe shrimp larvae exhibit rapid growth during the first year, especially between May and August (Table 3). *Pandalus danae* grows less rapidly after the first summer compared to other commercial deeper-water shrimp species because they produce sperm in the first autumn. In general, throughout the life of *P. danae*, growth slows during winter months because of the development of sperm in the fall and the effects of less favourable environmental conditions. Growth increases in summer months because sperm are not produced and environmental conditions improve. No growth occurs in ovigerous females because moulting cannot occur as long as eggs are being carried (Berkeley 1930). A logarithmic curve depicting coonstripe shrimp growth in Area 19 near Victoria is displayed in Fig. 2. Data were obtained from stock assessment surveys and biological sampling of commercial catches.

In general, coonstripe shrimp increase in weight in proportion to the cube of their lengths. Exceptions to this rule include:

1. the addition of weight increases at the beginning of each summer period of rapid growth;
2. the addition of weight slows from August in the first year to August in the second year and during the second period of male activity and the change of sex;
3. the addition of weight increases when shrimp become females;
4. weight drops quickly in March at the end of the third year when shrimp hatch their first batch of eggs (Berkeley 1930).

Locomotion

Coonstripe shrimp larvae opportunistically ride piggyback on small jellyfish having bell diameters similar to the leg span of the shrimp (Marliave and Mills 1993).

Shrimp use their walking legs and pleopods (found on the abdominal segments) to move along the sea floor or swim.

Coonstripe shrimp are evasive prey which flex their abdomens and use their tails in an escape response (Nemeth 1997a). Shrimp allow predators to approach to about 40 mm before escaping (Nemeth 1997b). The tail-flip escape response lasts about 30 ms followed by 60-70 ms of gliding. In total, shrimp travel about 15 cm at an average speed of 1 m/sec, 2-3 m/sec is common at the start of the tail-flip (Daniel and Meyhöfer 1989).

Trophic Relationships

Coonstripe shrimp are generally carnivorous benthic feeders that graze on smaller crustaceans (i.e., amphipods), polychaetes (e.g., *Sabellaria cementarium* and *Harmothoe* sp.) in Burrard Inlet (Butler 1980), mysids and detritus from plankton and large algae (Berkeley 1929b, Butler 1964, Neilson 1981). Shrimp probably feed on dead animal matter at times since they are attracted to traps baited with dead fish. However, there is little evidence of scavenging and shrimp in captivity do not generally eat anything that is not fresh. Shrimp larvae feed on microscopic plants and animals (Berkeley 1929b).

Predators of coonstripe shrimp include pelagic fish (Hart 1973) and groundfish (including flounders and lingcod) (Wilby 1937, Neilson 1981).

Parasites

The rhizocephalan *Sylon hippolytes* is a parasite (Calman 1898), though incidences of infestation appear to be low. Females are never ovigerous when host to this parasite (Butler 1980). Stock Assessment encountered a berried female prawn infected with *Sylon* sp., but the animal may have been infected after it was carrying eggs (J. Boutillier, Fisheries and Oceans Canada, pers. comm.).

When coonstripe shrimp larvae hitchhike on small hydrozoan jellyfish, the jellyfish usually die because the energetic demands of the increased locomotor effort are too high and they cannot feed properly. Coonstripe shrimp larvae are not considered to be parasites because they do not physically damage the jellyfish or take food from them. Rather, the association is closest related to the term phoresy, a non-parasitic association for obtaining transportation. The relationship between shrimp larvae and jellyfish differs from the classic definition of phoresy because the sizes of shrimps and medusae are similar and the relationship appears to be detrimental to one of the species (Marliave and Mills 1993).

Population Structure and Dynamics

Pandalus danae in British Columbian waters is basically an inshore and shallow water species. Coonstripe shrimp differ from deep-water species such as humpback shrimp (*Pandalus hypsinotus*), northern pink shrimp (*P. borealis*), prawns (*P. platyceros*), and sidestripe shrimp (*Pandalopsis dispar*) whose larvae tend to disappear from hatching grounds at about the third stage of development. Coonstripe shrimp dispersal appears to be limited (Berkeley 1930, Butler 1964) suggesting that there are probably many isolated unique populations of shrimp located throughout the inshore waters of B.C. These isolated populations have strong stock/recruitment processes and will be less susceptible to advection or influx of recruitment from other populations, i.e., few metapopulation effects. To date, there is little information available from which to base an informed decision on the resilience of coonstripe shrimp species and the compensatory mechanisms that populations may elicit under various exploitation rates. Available information from long-term coonstripe shrimp trap fisheries is not encouraging; a fishery that began in the Indian Arm area before World War II collapsed in the late 1960s. Furthermore, CPUE values generated from logbook records in Pacific Fisheries Management Area 20 show a general decline over time (Fig. 3). From commercial trap and trawl shrimp fisheries' catch log records, we do know that coonstripe shrimp coexist as a sub-dominant species in many areas of the coast, especially with prawns. This is why coonstripe shrimp in the past have largely been an incidental bycatch species in shrimp trap and trawl fisheries. Coonstripe shrimp are known to be the dominant shrimp species in a number of isolated areas, especially in PFMAs 18, 19, 20 and 28. A trap fishery has existed in several localized areas for many years; the trawl fishery began to target populations of coonstripe shrimp around 1995.

Fisheries for Coonstripe shrimp, *P. danae*

U.S.A.

- Alaska

Coonstripe shrimp occur incidentally in trap and trawl shrimp fisheries throughout Alaska - there are no directed fisheries for this species of shrimp (Paul Anderson, National Marine Fishery Service and David Love, Alaska Department of Fish and Game, pers comm.).

- Washington

Directed trap and trawl coonstripe shrimp fisheries occur in Puget Sound. The area is divided into 15 sub-areas where quotas for shrimp, not including spot prawns, are established. Not all areas are fished due to lack of interest. Quotas are based on historic catches from areas, as well as in-season adjustments based on CPUE. No directed assessment or biological information is gathered. In 2000, 70% and 6% of the shrimp (not including prawns) landed by the trap and trawl fisheries respectively were coonstripe shrimp. The trap fishery landed 12 tonnes of coonstripe shrimp, the trawl fishery 22 tonnes (T. Cain pers. comm.).

- Oregon

Coonstripe shrimp occur incidentally in trap and trawl shrimp fisheries. There have been a few attempts at a trap-only fishery under the guidelines for new fisheries, but it is very limited. The only restriction for the fishery under the Developmental Fisheries Program is that traps have to be used (Bob Hannah, Oregon Department of Fish and Game, pers. comm.).

- California

Coonstripe shrimp are exploited along the northern California coast as bycatch in the shrimp trawl and crab trap fisheries. California has no restrictions on a directed fishery for coonstripe shrimp. It is almost exclusively a trap fishery. A control date and a species specific permit were proposed this year, but will not be implemented until the next fishing season (April 1, 2002) if approved by the Fish and Game Commission in February 2002 (K. Barsky, California Department of Fish and Game, pers. comm.).

There have been relatively new (since 1995) directed commercial and sports fisheries for coonstripe shrimp developed in the Crescent City area off St. George Reef. Currently, restrictions on the commercial fishery under their guidelines for new fisheries are: 1) it is a trap-only fishery; 2) the fishery is closed during the egg-bearing season (November through March); and 3) the total number of licenses is limited (K. Barsky, California Department of Fish and Game, pers. comm.). The commercial fishery is directed at a live market and the average price in 1998 for coonstripe shrimp was around $9 (US) per kilogram. Although the commercial fishery is relatively small (36 tonnes), it is the eighth most valuable fishery for the Crescent City Port (Warner 1998).

In the Crescent City area, the sports fishery limit increased in 1997 from 35 coonstripe shrimp per day to approximately 9 kilograms per day. Recreational exploitation is currently believed to be minimal (Warner, 1998).

Canada – British Columbia

- Recreational

Prawns are usually the target species in the recreational fishery, and coonstripe shrimp incidentally caught. The fishery is open coast-wide throughout the year, but local areas are closed when prawn spawner index levels are at or below the baseline spawner index (Fisheries and Oceans Canada 2001b). Recreational fishers are required to purchase a sport fishing license to exploit shrimp. Traps must be used - trawl gear are not allowed (Fisheries and Oceans Canada 2001c). In Howe Sound and Burrard Inlet/Indian Arm areas, prawns are targeted and coonstripe shrimp incidentally caught. Traps are generally used, although occasionally divers exploit the shrimp. The level of exploitation of coonstripe shrimp is unknown, but is believed to be minimal (Dave Loop, Fisheries Officer, Fisheries and Oceans Canada, pers. comm.). Fishers in Sidney and Sooke target coonstripe shrimp. They place traps around wharves during fall evenings to collect the small male shrimp that have migrated into shallower waters. The fishery generally occurs from October to April, the main effort is concentrated from November until January or February (Richard Christenson, Fisheries Officer, Fisheries and Oceans Canada, pers. comm.).

- First Nations

First Nations can access shrimp for food, social and ceremonial purposes throughout the year (Fisheries and Oceans Canada 2001b). Communal licenses are issued to First Nation organisations; these licenses can be amended in season for resource conservation purposes. Traps, rather than trawl gear, are normally used (Fisheries and Oceans Canada 2001c). Prawns are targeted and exploited in Saanich Inlet and around Powell River, Ladysmith, Beaver Cove and Bella Bella (Fisheries and Oceans Canada, 2001b). The level of exploitation of coonstripe shrimp is unknown.

- Aquaculture

Lietz and Marliave (1984) describe their results from culturing coonstripe shrimp in indoor and outdoor ponds. The authors concluded that the species is amenable to culture through its entire life cycle and that rearing juveniles indoors and outdoors yields high growth rates relative to wild shrimp. However, they decided that cost-effective commercial culture of *P. danae* is probably not feasible - only an extensive outdoor culture system, which could obviate major food input costs, might prove to be commercially feasible. In addition, marketing the smallest sizes, without over-wintering, would be most profitable. A possible alternative could be extensive culture in shoreline impoundments. Castell et al. (1989) report that *P. danae* accepts two Standard Reference Diets (SRD) BML 81 S and HFX-CRD 84.

- Commercial

Coonstripe shrimp are generally caught incidentally in the prawn trap and shrimp trawl fisheries in British Columbia. There has been a directed trap fishery for coonstripe shrimp in the early 1900s at Victoria, the Burrard Inlet area (between Second Narrows and Deep Cove; Area 28), and Sooke Basin (Area 20), where a fishery continues today. The trawl fishery targets coonstripe shrimp off Sidney and Victoria (Areas 18 and 19) (Fig. 4). The total landings for both fisheries combined reached a high of 94 tonnes in 1997, although most of the landings were generated from the trawl fishery (Fig. 5). The Minister of Fisheries and Oceans put restrictions on expansion of the fisheries in 1998. Note: PFMAs 18, 19, 20 and 28 are equivalent to Shrimp Management Areas (SMA) 18, 19, 20 and FR respectively.

Trap Fishery

The directed trap fishery for coonstripe shrimp has had a varied history of assessment and management. The fishery in Burrard Inlet (Area 28), prior to World War II and for 20 years after, contributed significantly to B.C.'s annual shrimp landings. However, by the late 1960s coonstripe shrimp were no longer present in commercial quantities and the populations never seemed to have recovered (Butler 1980). The fishery, which occurred mainly from Second Narrows to Burnaby Shoals, was self-managed in the 1950s and 1960s whereby fishermen agreed amongst themselves to only pull their traps every second day.

Shrimp trap fishery logbook records from 1980-2000 show small landings of coonstripe shrimp from almost all the inshore statistical areas of the coast that are exploited in the prawn fishery with the exception of the westerly portions of Vancouver Island. The largest and most consistent coonstripe shrimp catches in the trap fishery have occurred in Area 20, in Sooke Basin. Since 1980, the fishery in this area has reported average landings of 9.7 tonnes per year of coonstripe shrimp; catches range from a low of <1 tonne in 1980 and 2000 to a high of 32 tonnes in 1981 (Fig. 5). Twenty-six vessels have fished in Area 20 since 1980 - one vessel fished in 13 different years, other vessels fished only in one year. In 2000, there were two vessels in the area trapping coonstripe shrimp.

The trap fishery in Sooke was managed in the 1980's with openings and closings based on the discretion of fishery officers. In the early 1980s, some assessment modelling of the area was done using saleslip data - a MSY was calculated to be approximately 15 tonnes, although at that time it was recognised that the population was below Bmax and a more precautionary Total Allowable Catch (TAC) was recommended. Fishers were concerned about the reliability of saleslip data and in the 1981/82 fishing season they agreed to fill out and submit logbooks. In-season management decisions were based on log records data and sampling of the commercial catch. In 1986 a pre-season test fishery was conducted prior to the opening of the fishery because of a lack of 2+ animals the previous year. From the late 1980's to the present, the fishery has not been assessed and the only management actions are short openings combined with restrictions on trap numbers. Catch Per Unit Effort (CPUE) data from log records show a declining trend in annual fishing success (Fig. 3). Coonstripe shrimp landings decreased to less then one tonne in 2000, although there is anticipation that 2001 will be a better year because sport fishers in the area are reporting good catches.

Trawl Fishery

Shrimp trawling has occurred in Areas 18, 19 and 28 for a number of years, primarily for pink, sidestripe and coonstripe shrimp (Fig. 6). Trawlers began targeting coonstripe shrimp in Areas 18 and 19 in 1995 and landings (approximately 92 tonnes) peaked in 1997 (Fig. 5). Trawl logbook records in Areas 18, 19 and 28 from 1995 to 2000 show that the trawl fishery has, on average, landed 48 tonnes of coonstripe shrimp each year. Catches range from a low of 4 tonnes in Area 18 in 1995 to 92 tonnes in 1997 in all areas combined (Fig. 5). The major landings in the trawl fishery are in Area 19 where 55 tonnes were removed in 1997. Landings in Area 28 are small compared to Areas 18 and 19.

In Area 18, since 1995, the coonstripe shrimp proportion of shrimp trawl catches has ranged between 6% and 31%. Catches have generally consisted of pink and coonstripe, with some sidestripe shrimp as well.

Fifty-three vessels have fished in Area 18 since 1995, some boats returning in four different years, other boats fishing for only one year. Two boats were present in 1995, 35 boats in 1998 and six boats in 2001. Catches were not evenly distributed among vessels – each year the top two boats caught 38-77% of the catch.

In Area 19, since 1996, the coonstripe shrimp proportion of shrimp trawl catches has ranged between 53% and 84%. Catches generally consisted of coonstripe and pink shrimp. Fifty-four vessels have fished in Area 19 since 1996, some boats returning in six different years, other boats for only one year. Five boats were present in 1996, 30 boats in 1999 and ten boats in 2001. Catches were not evenly distributed among vessels – each year the top three to four boats caught 46-99% of the catch.

In all areas of B.C.'s coast, but not including Areas 18, 19 and 20, the coonstripe shrimp proportion of shrimp trawl catches has ranged between 0% and 4%, since 1995. Catches generally consisted of pink and sidestripe shrimp.

Since 1998, select fishing grounds within Areas 18 and 19 have been assessed using fishery independent area swept trawl and trap surveys that are completed as part of the shrimp trawl assessment program. These assessments are used to set quotas for the major species of shrimp (there are six Pandalid shrimp species in these areas, but only four species are in sufficient quantities to assess annually). In 2001, assessments were extrapolated onto additional fishing grounds in these areas using logbook and survey data. The results of these surveys, as well as the resulting management actions, are compiled and made available to the industry as a "shrimp bulletin". These bulletins are also placed on the Shellfish Management web site (www.pbs.dfo.ca/ops/fm/shellfish/shrimp/Surveys/surveys.htm).

In Areas 18 and 19, CPUE data were generated to reflect the directed coonstripe trawl fishery; only tows where the weight of coonstripe shrimp was greater then any other shrimp species in catches were used to generate CPUE values (Table 4). Trends in fishery dependent logbook data and fishery independent survey indices of abundance do not track each other well. There are two possible reasons for the discrepancies observed. First, fishing methods have changed in recent years. Vessels began targeting coonstripe shrimp by using short tows in small pockets of high density shrimp, leading to higher CPUE estimates. Second, shrimp surveys conducted by Stock Assessment have experienced difficulties; sometimes the fish exclusion device used in the trawl net gets clogged with kelp and traps move along the bottom in high tidal areas. The consequence of these difficulties experienced by Stock Assessment is smaller shrimp catches.

Recently, commercial fishers have been targeting coonstripe shrimp in Areas 18 and 19. The winter live market brings the highest prices for coonstripe shrimp; fishers targeting this market repeatedly exploit small specific locations where coonstripe shrimp stocks are relatively homogenous. Bycatch of other shrimp species is minimal. Tow times are shorter (~20 minutes), the catch is hand-sorted and only the larger coonstripe shrimp size classes are retained (D. Rutherford, Fisheries and Oceans Canada, pers. comm.).

Discussion

Data Availability and Quality

Data availability and quality is dependent on the type of shrimp fishery. Little information is available from recreational and aboriginal fishers because they are not required to submit catch reports. Directed commercial fisheries for coonstripe shrimp occur in Sidney, Victoria, and Sooke areas; Fishery Officers have collected some anecdotal information regarding fishing activities in these areas.

Commercial shrimp trap and trawl fisheries provide fishery dependant information. Conditions of license require vessels to provide saleslip reports of landings and values and logbook reports (mandatory since 1987) of location, effort and catch. Before 1996, fishermen were either unwilling or unable to separate catch by species, especially coonstripe and humpback shrimp (*P. hypsinotus*) (Boutillier and Joyce 1998). There were also some earlier problems with reporting of the correct species in the north coast where humpback shrimp were reported as coonstripe shrimp. Consequently, logbook data pertaining to coonstripe shrimp fishing are not reliable prior to the mid 1990s, especially in northern areas. Some commercial sampling by charter and patrol vessels has occurred. There is partial observer coverage; however, the focus of this monitoring program is bycatch composition rather than shrimp catches.

Fishery independent data have been collected since 1998 by area swept trawl surveys that are completed as part of the shrimp trawl assessment program for setting quotas (Boutillier et al. 1999). Recently, biomass estimates for coonstripe shrimp have been extended beyond trawlable areas due to the trapping in the surveys.

Regulatory Approaches

Directed coonstripe shrimp fisheries can be managed to meet two biological objectives: 1) to prevent recruitment overfishing, using either a fixed exploitation rate or a fixed escapement target; and 2) to prevent growth overfishing, using size limits. Regulatory strategic choices designed to control recruitment and growth overfishing in coonstripe shrimp fisheries are discussed below. In addition, procedures currently in place to regulate coonstripe shrimp fishing effort, which include effort limits, area/time closures and inseason effort assessment (tagging) (from Perry et al. 1999), are also examined.

Recruitment Overfishing

Fixed exploitation rate

A fixed exploitation rate was introduced to the shrimp trawl fishery in 1997. There was no management of recruitment overfishing in the trawl fishery prior to this time (Boutillier et al. 1999). Biomass surveys, fixed exploitation rates and quotas are tools used to manage the shrimp trawl fishery in Areas 18 and 19. An initial TAC is set for commercially targeted shrimp species based on the previous year's biomass estimates. When a predetermined percentage of the TAC is exploited, the fishery is closed and in-season fishery independent assessment surveys are done to produce estimates of harvestable stock sizes from which yearly quotas are derived by multiplying stock estimates by an exploitation rate (Perry et al. 1999) of 25 or 33%.

Developing a management system that is based on a fixed exploitation rate requires information on the sizes of shrimp stocks. In the trawl fishery, a survey methodology is used that combines an area-swept trawl density estimate with a trap survey that compares the relative density of animals in trawlable and untrawlable areas. Where appropriate, the index area biomass indices are 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 survey methodology currently used in Areas 18 and 19 was developed for mixed shrimp species exploited by the trawl fishery rather than for a targeted coonstripe shrimp fishery. There are two problems associated with the current methodology. First, there is potential for large errors in annual biomass estimates (Perry et al. 1999). There may be much variation in shrimp stock populations between months. Second, surveys generally do not encompass the small areas where fishers are targeting coonstripe shrimp. Instead, surveys are done where commercial fishing intensity was generally high, but in many cases shrimpers had targeted pink or sidestripe rather than coonstripe shrimp. Coonstripe shrimp stocks in Areas 18 and 19 should be identified with input from stakeholders and the Shrimp Trawl Sectoral Committee (STSC) and from assessment survey and landings data. It is critical to determine the appropriate spatial scales of coonstripe stocks; setting the unit stock size too large risks including a number of separate stocks, which are then vulnerable to serial depletion (Perry et al. 1999). Identified coonstripe shrimp stocks should be surveyed separately from the regular assessment surveys done in Areas 18 and 19 designed to set quotas for mixed shrimp stocks. However, developing biomass estimates for a number of stocks is expensive and keeping track of the catch by species from each small area would require some type of validation system.

Fishery independent survey assessments are used primarily to index trends in shrimp abundance and secondly to determine exploitation quotas. There are two problems associated with the way shrimp quotas are managed. First, although quotas are established for individual shrimp species in Areas 18 and 19, an area will be closed to fishing if any one of the species' quotas is reached. This means that fishers targeting coonstripe shrimp can no longer exploit this species just because, for example, the sidestripe quota was reached first. One solution is to set quotas specifically for identified coonstripe shrimp stocks. Another solution is to manage PFMAs on a subarea rather than on an area basis. Instead of closing entire areas when one shrimp species quota is reached, subareas could remain open for fishing where assessment surveys have shown that coonstripe shrimp are the most prevalent shrimp species. A third solution is to grant scientific or experimental licenses to interested shrimpers who still wish to exploit coonstripe shrimp in an area just closed. These licenses would ensure that coonstripe shrimp fishing occurs in a carefully monitored environment (i.e., with on-board observers monitoring bycatch and collecting biological data) (Fisheries and Oceans Canada 2001c). The second problem with the way shrimp quotas are managed is: quotas are set and monitored based on the assumption that individuals caught and landed are representative of the entire population. When fishers target just the largest oldest component of the stock, assumptions around the quota and monitoring system become problematic. Quotas should be established specifically for larger sizes/year classes because fishers are targeting larger individuals, as there is market demand for this type of product. Small-sized shrimp are being discarded and are not reported against the overall quota. Impacts of this harvesting selectivity need to be understood.

A fixed exploitation rate is not currently used as a management tool for the coonstripe shrimp trap fishery in Area 20. Here, effort is limited with short openings and restrictions on trap numbers.

Fixed escapement

A fixed exploitation rate is not currently used as a management tool for prawn stocks, as there is no estimate of coastal biomass (Fisheries and Oceans Canada 2001b). The prawn trap fishery has been managed using an index of female spawners 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 1988a,b, Boutillier and Bond 1999) and has been modified to reflect a better understanding of the stock/recruitment relationship. The escapement index is monitored using in-season at-sea sampling of the commercial catch per trap of the female cohort.

Developing a fixed escapement management system for coonstripe shrimp, similar to prawns, is complicated because of the biology of the animal. For prawns, which are semelparous, 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 coonstripe shrimp because of their ability to skip the male phase to become primary females and to produce more than one batch of eggs (being multiparous). Primary females are probably not as fecund as larger older 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 would 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 has a history of stable fishing and empirical survey data on which to base the spawner index, the coonstripe fishery does not have this long-term historical data set from which to base even a preliminary escapement index. Consequently, a fixed escapement policy is currently not possible for directed coonstripe shrimp fisheries. The policy could work well for the trap fishery, but may not be appropriate for the trawl fishery because of fishing gear-related mortality. Research needs to be done in the trawl fishery to examine whether short tows and hand-sorting of catches are effective in terms of returning bycatch to the sea unharmed.

A spawner index is based on stock/recruitment productivity models and theory and has particular data requirements. The mean numbers of coonstripe shrimp female spawners per trap in March and early April (at the time of egg hatching) are needed. Catch, effort, proportions-at-age and natural mortality estimates are required for cohort analysis. Natural mortality rates are also required to determine spawner indices for the months prior to the March/April hatching period. In addition, the fecundity of shrimp (number of eggs per adult female) is required for Ricker stock recruitment analysis. All these data can be captured using: 1) a detailed commercial logbook program (for total hailed catch, effort and CPUE); 2) a commercial biological sampling program where sampling occurs at the start and end of commercial openings (for catch composition including sex and size (from length and weight measurements) and age composition of catch); and 3) survey cruises during fishing closures (for independent pre and post fishing assessments, establishing relative indices of natural mortality and recruitment and verifying commercial sampling information). It is also useful to have an area closed to fishing to provide the opportunity to collect data from areas with varied fishing patterns. More details regarding the spawner index and the way it is calculated can be found in Boutillier (1996).

Growth Overfishing

Size limits

Size limits mean there is a minimal or maximal exploitable size, or both. A minimum size limit, in conjunction with size selective trap escapement mechanisms, have been effective management tools in the prawn fishery. The trap industry recognises the benefits accrued by the size limit for prawns because market prices are higher for larger prawns and it prevents lower yield exploitation practises (Boutillier 1984, 1985).

Currently, there is no minimal size limit enforced for shrimp species other than prawns, except through gear mesh size restrictions which allow smaller animals to escape. Fishers using prawn traps catch only larger shrimp because of the large mesh size inherent to this trap type. But in Area 20 (Sooke Basin), no mesh size restrictions are enforced - any web size may be used in this trap fishery (Fisheries and Oceans Canada 2001b). But fishers have deemed prawn traps to be less effective at catching coonstripe shrimp compared to cedar traps; consequently, the latter trap type is the only one used in Sooke Basin. The wood panels on cedar traps are generally narrowly spaced; therefore, wood traps catch more small-sized coonstripe shrimp than prawn traps. However, market demand for larger product, especially for live coonstripe shrimp, has implemented voluntary size limits in coonstripe shrimp fisheries. Generally, fishers sort their catch by hand and keep only the larger product. Setting and implementing a size limit on shrimp in a trap fishery would be a fairly simple matter considering the history and technology that the prawn trap industry is presently employing. But if the optimum size range varies from the prawn industry and the escapement modifications were reduced for the coonstripe shrimp trap fishery, this would lead to a complicated enforcement plan for trap mesh restrictions in the shrimp trap fishery for two species which often co-habitat. This, however, has been done in Area 20 with the relaxation of mesh requirements in the coonstripe shrimp fishery, combined with staggered openings and non-retention of prawns.

There are no growth overfishing management controls in the shrimp trawl fishery. Development of size selective gear modifications is being experimented with in the industry for the sidestripe fishery, but there is no proven technology presently employed. The shrimp trawl industry repeatedly complains about the small shrimp in the spring and recommendations have been made (Boutillier 1988, 1993) to take advantage of the rapid growth rates during this time. The shrimp trawl fishery is changing and size targeting is occurring through the practises of short sets and hand-sorting of catches. Small shrimp and non-target species are released; however, it is unknown how much handling mortality occurs. In general, fishery gear-related mortality is probably high. Even if short tows and hand-sorting prove to enhance bycatch survival, it would be difficult or impossible to regulate this activity. Fishers trawling for coonstripe shrimp may opt to use nets with larger mesh sizes (such as those used to collect sidestripe shrimp) in order to limit bycatch and sorting time. Implementing a size limit in the shrimp trawl fishery would not be as reliable as in the trap 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 requires information on the growth and mortality of coonstripe shrimp, and an understanding of the ex-vessel prices for shrimp and how that might vary by size and product type.

Annual variations in coonstripe shrimp growth rates may occur depending on such factors as density and environmental conditions, but also on the proportion of primary females in a population. Primary females will not grow if they are carrying eggs, whereas males of the same cohort will continue to grow during the winter period. Information on the proportion of the population that will be primary females would be required to provide an optimal yield per recruit model. The on-set of primary females may be controlled through phenotypic or genotypic expression. If control is phenotypic, then the onset of primary females will be dictated by environmental conditions that probably change every year in each area. Primary females are a compensatory mechanism evolved to protect populations from stress such as extreme environmental conditions. They may be more prevalent in populations living at the extremes of their ranges or in shallower water. If control is genotypic, then selection for large shrimp may ultimately reduce the overall size structure of a population. A single coast-wide size limit might be established for coonstripe shrimp fisheries, but it would experience the same problem as in the prawn fishery where optimal size limits vary considerably between areas (Boutillier 1985).

Industry indicates that coonstripe shrimp caught in trawls are landed in three forms: live, graded fresh and small peeled product. Prices vary depending on product type; prices for live product range between \$7.70-13.20 per kilogram, while the price for peeled product is presently about \$0.50 per kilogram. It should be noted that there is a difference whether the maximum catch is obtained from the entire population or from a certain segment of the population. Large shrimp, which are normally age 2+ females, are most desirable from a market point of view because the addition of weight increases when shrimp become female. The addition of weight is due to the development of eggs and a slight increase in proportional weight of the body (Berkeley 1930).

Direct effort regulation

Effort limits

Early control of the build-up of fishing effort is an important management measure that should be taken to protect against the overexploitation and uncertainties associated with developing invertebrate fisheries (Perry et al. 1999). Clark et al. (1985) describe an approach to estimating optimal capacity that is based on limited knowledge (e.g. of recruitment) that may be applicable to developing fisheries, in particular for mobile species such as shrimp.

In the shrimp trawl fishery during 2000/01, there were 248 licenses issued of which 198 actively fished; there is concern regarding the current capacity of the fleet (Fisheries and Oceans Canada 2001c). In the shrimp trap fishery during 2000/01, there were 252 license eligibilities (Fisheries and Oceans Canada 2001b). Development of directed fisheries specifically for coonstripe shrimp, which is available to the 500 vessels presently allowed to operate in shrimp trawl and trap fisheries, would be unmanageable. In most areas of the coast, coonstripe shrimp will probably remain as bycatch in the trap and trawl fisheries; however, in the few specific locations in Areas 18 and 19 that would support a directed coonstripe shrimp fishery, effort control should be considered. Effort has been controlled in the commercial trap fishery in Area 20 since the 1980s through restrictions on trap numbers (maximum number per vessel is currently 50 traps) (Fisheries and Oceans Canada 2001b). Although there are trap volume restrictions in the prawn fishery (Fisheries and Oceans Canada 2001b), there are none so far in the coonstripe trap fishery in Area 20. Effort has inadvertently been controlled in Area 20 because regular prawn traps are not effective in catching coonstripe shrimp; only the unique cedar traps are effective and these trap are labour intensive to build and maintain and are not owned by the average shrimper.

Area / time closures

Establishing reserves designed to protect coonstripe shrimp populations has not yet been done. Reserves should be established within identified coonstripe shrimp stock areas and fishing prohibited. These reserves would protect against the overexploitation and uncertainties associated with the developing fishery. Such reserves must include some locations of prime habitat and large aggregations of shrimp. Directed studies could be undertaken in the reserves to determine coonstripe shrimp growth and mortality rates (Perry et al. 1999), the latter being especially useful for calculating a spawner index (Boutillier 1996). These studies would provide more information if compared to similar studies in locations subjected to fishing. Documenting natural variations in unfished populations would provide estimates of risks associated with the limit reference point - the limit reference point for population levels should not allow populations to fall below maximum productivity which, according to Zheng et al. (1993), is 25% of the virgin biomass. Further surveys would be conducted or fishing activities allowed in unfished areas in order to ‘prove the production potential’ of such areas and increase the minimum biomass estimates (Perry et al. 1999).

Time closures are not a management tool currently used in the trawl fishery in Areas 18 and 19. An area is closed only when one of the quotas assigned to the various commercial shrimp species is reached. If none of the established quotas are reached, then an area will remain open all year. Time closures (i.e., short openings) are used in Area 20 to control effort in the coonstripe shrimp trap fishery. This fishery occurs from November 1 to December 31, but can be varied for conservation or other management purposes (Fisheries and Oceans Canada 2001b). However, the danger in using only short openings to control effort is that a large number of vessels could theoretically fish the resource during the short opening.

Inseason effort assessment (tagging)

Post-larval prawns have been tagged in Howe Sound in order to understand spatial movement patterns and provide information on immigration and emigration (Boutillier 1996). Tags were inserted through an animal's abdomen, specifically the second and third abdominal segments. Tagging has not yet been done with coonstripe shrimp, but it is a valid, although difficult and expensive, method for regulating exploitation rates or providing population estimates. Coonstripe shrimp would have to be tagged, released alive, allowed to randomly mix throughout the population, and then recaptured. Tagging should occur between moults because it is unclear whether shrimp can successfully moult while they are tagged. Some tagged individuals would have to be kept in traps to monitor their survival rates (J. Boutillier, Fisheries and Oceans Canada, pers. comm.).

Other Assessment and Management Issues

Bycatch and Collateral Damage

Bycatch is a problem in both the trap and trawl fisheries. In the trap fishery, the major bycatch is restricted to those animals that can enter small tunnels and not escape through the 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 (Boutillier 1996). In the prawn trap fishery, mesh size restrictions for the traps and tunnels improve sorting of undersized prawns on the bottom. All catch must be sorted immediately when traps are recovered to the vessel and undersized prawns, berried prawns and bycatch must be released unharmed. In addition, gear can only be hauled once each day to limit handling of prawns. In general, bycatch is not considered to be significant in the prawn trap fishery. In Sooke Basin in Area 20, since there are no mesh size restrictions in place, smaller animals are caught in traps. However, prawns cannot be retained (Fisheries and Oceans Canada 2001b) and their numbers are generally considered to be low in the basin (usually less than 5% of the shrimp species caught).

The diversity of animals brought up in trawl nets is 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, which was implemented in the 2000-fishing plan). These grates and panels sort the catch while the trawl is on the bottom, but there is no information on the survival rate of the animals that are released, including fishery-related mortality of juvenile shrimp. The grates are very effective in eliminating 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. Industry has been working to rectify this problem through the use of rigid, hard-mesh panels in the head of the trawl. This was implemented in 2001 in all otter trawls at the request of the industry. Bycatch collected from Areas 18 and 19 in shrimp trawl assessment surveys is detailed in Fig. 7. In Area 18, from 1987-2001, prawns represented less than 8.5% of the commercial shrimp species caught. In Area 19, from 1996-2001, prawns represented less than 1% of the shrimp species caught. Bycatch from an otter trawl vessel exploiting coonstripe shrimp in Areas 18 and 19 for the live market was minimal, consisting mainly of squat lobster and spiny lebbid shrimp. The biomass of prawns and pollock collected by this vessel was very low (D. Rutherford, Fisheries and Oceans Canada, pers. comm.). Regardless of these preliminary data, bycatch is a serious issue in shrimp fisheries and an observer program to monitor bycatch should be considered for directed trawl and trap coonstripe shrimp fisheries.

The Policy on Selective Fisheries is in place to eliminate the impact of fisheries on bycatch of other species or of the select component of the target species. Under the experiment protocol for these fisheries, it would be possible to find the most selective gear or fishing method that insures meeting selective fishing standards. This selective fishing method should be utilized regardless of whether coonstripe shrimp fisheries are being pursued by the shrimp trap or trawl industries. It may be that different areas have different sensitivities and would require different fishing standards. The PSARC Habitat Subcommittee should discuss an environmental assessment framework for directed coonstripe shrimp fisheries in the designated areas.

Although bycatch may be reduced in shrimp fisheries through technological innovations or changes in exploitation methods, both long-lined trap and trawl gear are capable of causing collateral damage to habitats, especially sessile habitat forming organisms such as sponges and corals. Bottom trawling likely causes more extensive physical damage to benthic communities than trapping. Impacts will vary by area and species, but as the fisheries grow, fishing will occur in more areas that have not been previously exploited or surveyed. A priority should be made to understand the environmental impacts of the trap and trawl fisheries. If collateral damage is shown to be considerably less using trap rather than trawl gear, directed coonstripe shrimp fisheries could move toward a trap-only fishery. This action would also solve potential gear conflicts that may arise. This is discussed below in more detail.

Allocation

Coonstripe shrimp stocks identified in Areas 18 and 19 should be allocated to shrimpers who wish to directly target this shrimp species and not to shrimpers who wish to target mixed shrimp stocks. Allocating coonstripe shrimp stocks between the trap and trawl industries will be complicated because all areas can be fished with traps, but not all areas can be trawled. Thus, there is potential for gear conflicts in some areas. Washington State has dealt with this problem in the offshore spot prawn fishery by converting trawl licenses with the appropriate fishing history to trap licenses and will make the fishery trap-only by 2003.

Cost

Prior to the 2002/2003 fishery, shrimp trawl license holders paid management fees totaling $349,000. Of this amount, the stock assessment program, catch sampling program and Fisheries and Oceans staff accounted for $152,500. In addition to the co-management programs funded by licence holders, the cost to Fisheries and Oceans Canada for the trawl fishery is $290,000 annually (this includes management, stock assessment, enforcement and other activities, including licensing and administration). [Note: a new co-management arrangement is under discussion and is currently scheduled to be developed prior to implementation of the 2002/2003 shrimp trawl fishery. Management programs and funding support for the Department's management, assessment and enforcement activities will be derived through a joint project agreement with a representative industry organization (Fisheries and Oceans Canada 2001c)].

In the shrimp trap fishery, annual costs to Fisheries and Oceans Canada total approximately $233,000 (in 1997), with stock assessment accounting for $116,000. The management fee per license holder ranges between $1,200 and $1,600 which pays for arrangements with an industry service provider for the delivery of in-season information. An additional $100,000 will probably be required to finance the industry's new responsibilities, which include delivering fishing plans and enforcing the single haul management measure cost wide (Fisheries and Oceans Canada 2001b).

The cost associated with doing additional assessment surveys on identified coonstripe shrimp stocks is outlined below. Costs associated with bycatch or catch validation monitoring programs that will likely be needed for directed coonstripe shrimp fisheries have not been estimated. The cost to Fisheries and Oceans Canada Science Branch, Pacific Region, for use of the research vessel "Royal Bounty" for assessment surveys is approximately $1,200 per day (this includes crew wages, fuel and food). Salaries per day for the services of a biologist ($200) and a technician ($180) would be roughly $380. Additional lab work for a technician after the assessment survey is completed would be approximately 1.5 days per stock surveyed. Hypothetically then, if six coonstripe shrimp populations were surveyed once in Areas 18 and 19, the total cost of this endeavour to Fisheries and Oceans Canada would be approximately $9,500. This amount is based on the following assumptions: 5 days on the research vessel (4 days towing and 1 day travelling, 1.5 stocks surveyed each day, 6 tows for each stock), 9 days lab time afterward for the technician (1,200 specimens collected for each stock for length frequency analyses, 800 shrimp analysed per day).

The Pacific Framework for Emerging Fisheries

Coonstripe shrimp fishing is not a new activity in Areas 18 and 19. These two areas have a long history of coonstripe shrimp being exploited with other shrimp species, mainly pink and sidestripe shrimp. However, in recent years, as the trawl fleet evolves, coonstripe shrimp are increasingly being targeted at various sites. The expectations of licence holders for the development of directed coonstripe shrimp fisheries has not been achieved within the current management framework for the shrimp fishery, which has focused primarily on pink and sidestripe shrimp (Fisheries and Oceans Canada 2001c). Shrimp managers will face a number of challenges in managing directed fisheries for coonstripe shrimp (refer to Recommendations section). No doubt some of these challenges can be tackled under the current management regime established for mixed shrimp species. However, including coonstripe shrimp fisheries under the Pacific framework for emerging fisheries would give managers more flexibility with regards to management and assessment options. These fisheries fall under the definition of emerging fisheries because coonstripe shrimp are a bycatch species that has now become a target species, the fisheries are data-limited, and coonstripe shrimp stocks are not fully utilized and not adequately covered under the current management plan. The New and Emerging Fisheries Policy is precautionary in its approach and it is designed to ensure conservation of stocks and the sustainable use of fisheries resources (Fisheries and Oceans Canada 2001a).

Data Requirements

The breadth of data required to effectively manage a new directed fishery is considerable. A cornerstone of the New and Emerging Fisheries Policy is provision for the establishment of a scientific base with which stock responses to new fishing pressures can be assessed. The process by which new fisheries are to be managed must include the requirement for stock assessment information in the early stages. Information on the abundance, distribution, and productivity of the target species is identified as the key scientific requirement for development of precautionary management strategies (Fisheries and Oceans Canada 2001a). More specifically, Perry et al. (1999) outline information that is required for managing developing fisheries. This information includes: 1) basic biological information such as population structure, distribution in time/space, preferred habitats, population size, size/age structure, reproductive characteristics, productivity characteristics; 2) potential fishing techniques; 3) potential for habitat disturbances; 4) potential market and value of product landed; and 5) response of target species to fishing.

With regards to coonstripe shrimp population dynamics, a particularly important aspect that requires more research is the notion that coonstripe shrimp populations are relatively discrete entities, as suggested by previous studies. Coonstripe shrimp populations may associate with bottom substrate or aggregate due to hydrographic processes. However, the degree of coonstripe shrimp larval containment in Areas 18, 19 and 20 is unknown and should be investigated using genetic research and instruments that measure hydrographic conditions.

Abiotic information should be collected in the area of coonstripe shrimp populations to determine how much of the variance in biological parameters, such as recruitment, natural mortality etc. can be explained by environmental conditions. Biotic information that will be necessary will be indices of abundance of various year classes, as well as condition indices which would, at a minimum, include sex, size, diseases, and fecundity. In particular, it would be useful to understand if the production of primary females is a genotypic or phenotypic response and incorporate this into the overall management of the stock. Fisheries specific information will be required to determine the cohorts and sizes of animals targeted by each gear type.

Conclusions

- The southern region of British Columbia, specifically Areas 18, 19 and 20, can support small directed fisheries for coonstripe shrimp.

- The current survey methodology and quota system designed for mixed shrimp stocks need to be modified for a directed coonstripe shrimp trawl fishery.

- A fixed escapement management system cannot be used to manage coonstripe shrimp fisheries at this time.

- Bycatch and collateral damage are serious issues in shrimp trap and trawl fisheries.

- There will be conflict regarding allocation between trap and trawl gear in directed coonstripe shrimp fisheries.

- Additional management costs will be required for directed coonstripe shrimp fisheries to pay for assessment surveys and programs designed to monitor bycatch and fisheries catches.

- Directed coonstripe shrimp fisheries should be included under the Pacific framework for emerging fisheries.

- More scientific research is required about coonstripe shrimp biology in Areas 18, 19 and 20.

Recommendations

1. Targeted coonstripe shrimp trap and trawl fisheries should be moved to fall under the Pacific framework for emerging fisheries and be managed in a risk adverse manner.

2. Directed coonstripe shrimp fisheries should initially be managed using a fixed exploitation rate with the intention of possibly moving towards a fixed escapement policy in the future. Precautionary target limit points for exploitation rates should be in the 25-33% range until stock dynamics are better understood.

3. Abiotic (environmental) and biotic information for coonstripe shrimp should be collected. Specific biotic information should include, but not be limited to, the appropriateness of fixed escapement targets, the discreteness of coonstripe shrimp populations, and the controls for determining the number of primary females (phenotypic or genotypic).

4. Fishery independent surveys currently conducted in Areas 18 and 19 for mixed shrimp stocks should be modified and expanded to provide meaningful assessment information and appropriate quotas for a directed coonstripe shrimp trawl fishery. Coonstripe shrimp stocks should be surveyed separately from other mixed shrimp stocks.

5. A catch validation/monitoring system should be implemented to monitor and understand fishery impacts in each coonstripe shrimp stock area from targeting particular size classes.

6. A bycatch monitoring program should be established in coonstripe shrimp trap and trawl fisheries to quantify the discard mortality of small sorted shrimp. The most selective fishing method or gear should be determined and utilized.

The following recommendations are new and were included during revisions of the original document after the PSARC Invertebrate Subcommittee meeting:

7. Coonstripe shrimp stocks in Areas 18, 19 and 20 should be identified, as the stock in Area 20, Sooke Basin, has been identified.

8. Quotas should be established specifically for identified coonstripe shrimp stocks, not just for mixed shrimp stocks as is currently done.

9. Quotas should be set specifically for the larger coonstripe shrimp size classes, and not for entire populations as is currently done, because it is the larger individuals that are being targeted.

10. Areas 18 and 19 should be managed on a subarea rather than on an area basis so that some subareas can remain open for shrimping when other subareas are closed. Currently, an area is closed to shrimp exploitation after any one of the shrimp species quotas is reached. This means that coonstripe shrimp fishing ceases in a particular area, even if the quota for this species has not been reached, when the quota for another shrimp species is attained.

11. If many coonstripe shrimp stocks are identified in Areas 18 and 19, some stocks should be protected from exploitation and used as sites for fishery-related research.

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Tables

Table 1: A summary of geographic information, depth and types of fisheries exploiting commercial species of Pandalid shrimp in B.C. coastal waters (Butler 1980, Boutillier and Joyce 1998).

Scientific Name	Common Name in B.C.	Geographic Information and Depth Range	Fisheries
Pandalus platyceros	Spot prawn	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 the protected inside waters, although they do occur in offshore regions of B.C.	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	Eastern Pacific from St. Matthew Island to Columbia River and western Pacific from Sea of Japan to the Okhotsk Sea. 16-1380 m. Most of the population is in protected inshore waters or nearshore areas of the north coast of B.C.	Series of small directed trawl fisheries in inshore and nearshore areas of B.C. Associated with small, relatively stable populations which were fished in some areas since the early 1900s.
P. jordani	Smooth pink shrimp	Eastern Pacific from Unalaska Island AK to San Nicholas Island, CA. 36-457 m. Major populations occur in offshore and nearshore regions of B.C. coastal waters from West Coast of Vancouver Island, Queen Charlotte Sound, Chatham Sound and some areas in the Georgia Strait.	Directed trawl fishery in B.C. offshore areas. 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. 5-450 m. Small isolated populations occur in inshore and nearshore regions in B.C.	Small, almost negligible, incidental catch in the inshore, nearshore trawl fisheries for shrimp.
P. hypsinotus	Humpback shrimp	Eastern Pacific from Norton Sound AK to Puget Sound WA. Western regions from western Bering Sea to the Sea of Japan and Korea Strait. 5-460 m. Small isolated populations associated with protected inshore waters in inlets in B.C. waters.	Incidental catches in both the trap and trawl fisheries with small directed trap fisheries in Masset Inlet and Prince Rupert Harbour and a small, directed trawl fishery in the Knight Inlet area. Misreported for years as Coonstripe shrimp in the northern fisheries.

Table 1 con't

Scientific Name	Common Name in B.C.	Geographic Information and Depth Range	Fisheries
P. danae	Coonstripe or Dock shrimp	Resurrection Bay/Aleutian Islands to Bahia San Quintin, Baja California. Intertidal to 185 m. Predominately occurs in small isolated populations in inshore areas of B.C.	Incidental catches in both the trap and trawl fisheries with a small, directed trap fishery in Area 20 and newly developed directed trawl fisheries in Areas 18 and 19.
Pandalopsis dispar	Sidestripe shrimp	Pribilof Islands, Bering Sea, to Manhattan Beach, OR. 46-649 m. Inshore, nearshore and offshore regions of B.C. coast. Highest densities appear to be in the inshore regions.	Mainly an incidental catch in the shrimp trawl, although the industry is now experimenting with the technology to target this species.

Table 2. Larval development stages of coonstripe shrimp, *Pandalus danae* (from Berkeley 1930).

Stages of Development	Size (mm) [a]	Distinguishing Characters
First	6	Eyes immobile; telson bearing 14 setae; uropods enclosed; transparent with red chromatophores.
Second	8	Eyes stalked; telson bearing 16 setae; uropods enclosed; color similar to first stage.
Third	9	Uropods free; inner ramus much smaller than the outer; telson triangular; 10 terminal setae.
Fourth	12	Rostrum with 8-10 dorsal spines; pleopods present as simple or slightly bilobed buds; telson almost rectangular; much larger than the third stage.
Fifth	14	Rostrum with 10-12 dorsal and 4-5 ventral spines; pleopods distinctly biramous, but not jointed and without setae.
Sixth +	17	Almost adult in character; exopodites of third maxilliped and pereiopods only shriveled remnants.
	20	Lost all exopodites; the arthrobranchiae are still primitive and the bud of the podobranchia has only just appeared on the second maxilliped; pleopods are sparsely setose.
	23	The arthrobranchiae and pleopods are well developed, though no secondary sexual characters have appeared; antennule is not fully developed.
		The pleurobranchiae develop fairly early, but the arthrobranchiae and podobranchia are usually not fully developed until some time after the shrimp loses most of its larval characters.
	≥30	The antennule is fully developed.

[a] Size is measured from the tip of the rostrum to the tip of the telson

Table 3: Size and growth of coonstripe shrimp, *Pandalus danae*.

Year	Sex	Month	Age (months)	Carapace Length (mm)	Total Length (mm)	Weight (g)	Notes	Source
First	Larva	March	<1		6			3
	Larva	May	2		9			3
	Immature	July-Aug	4-6		< 30-35		cannot tell sex	3
	Male	Oct	7	12.5-12.8	40-65	1.8		2, 3, 4
	Male				45		male characters appear	3
	Male				> 60		sexually active males	3
	Female		<8	13-17	60-70		"primary" females	3, 4, 5
Second	Male / Transitional	April	13	15.6	70-79	3.2		3, 4
	Male	Oct	19	17.3-18.7	70-88	4.4		2, 3, 4
	Female	Oct	19	18	85-87	4.9		3, 4
Third	Male / Transitional	April-June	24-27	18.7-19.3	85-98	5.5-6.0		3, 4
	Female	Oct	31	21.7-22.0	90-110	8.5		2, 3, 4
Fourth	Female				125-145, 220		unclear how long shrimps live	1, 3

Source: 1 = Berkeley (1926), 2 = Berkeley (1929a), 3 = Berkeley (1930), 4 = Butler (1964), 5 = Marliave (1977).

Table 4: the CPUE from trawl fishery logbook data and fishery independent survey biomass indices for coonstripe shrimp in PFMA 18 and 19. Numbers of vessels used to calculate the CPUE are listed in brackets.

Year	CPUE (kg/min towed)		Survey Biomass (t)	
	PFMA		PFMA	
	18	19	18	19
1996	1.18 (9)	1.47 (5)		
1997	0.55 (22)	0.78 (23)		
1998	0.36 (29)	0.50 (17)	15	96
1999	0.86 (13)	0.83 (28)	27	60
2000	1.31 (5)	0.87 (24)	22	110
2001	0.17 (4)	0.56 (12)	23	64[1]

[1] The 2001 estimation procedure has changed for 2001 to reflect abundances in unfished areas. Previous surveys have not been recalculated using the new methodology.

Figures

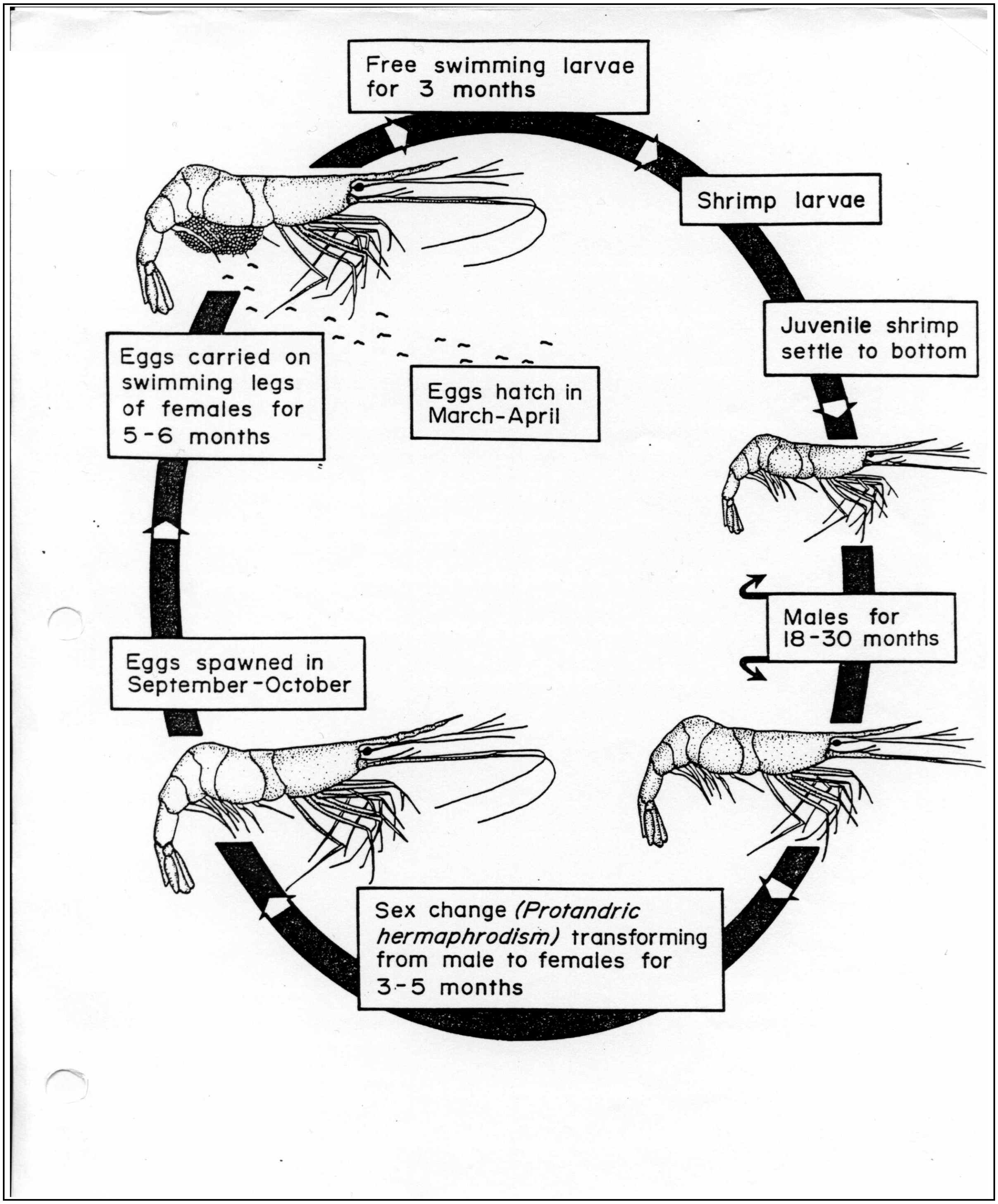


Figure 1: Generalized life history of pandalid shrimp.

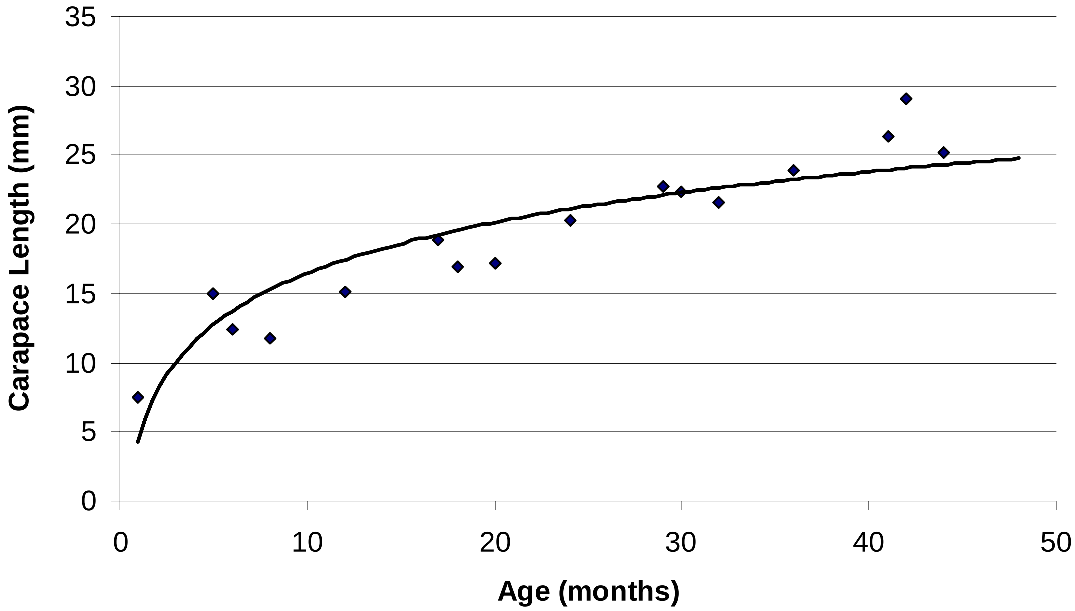


Figure 2: Growth curve for coonstripe shrimp, *Pandalus danae*, in Area 19. Data were collected from 1995-2001.

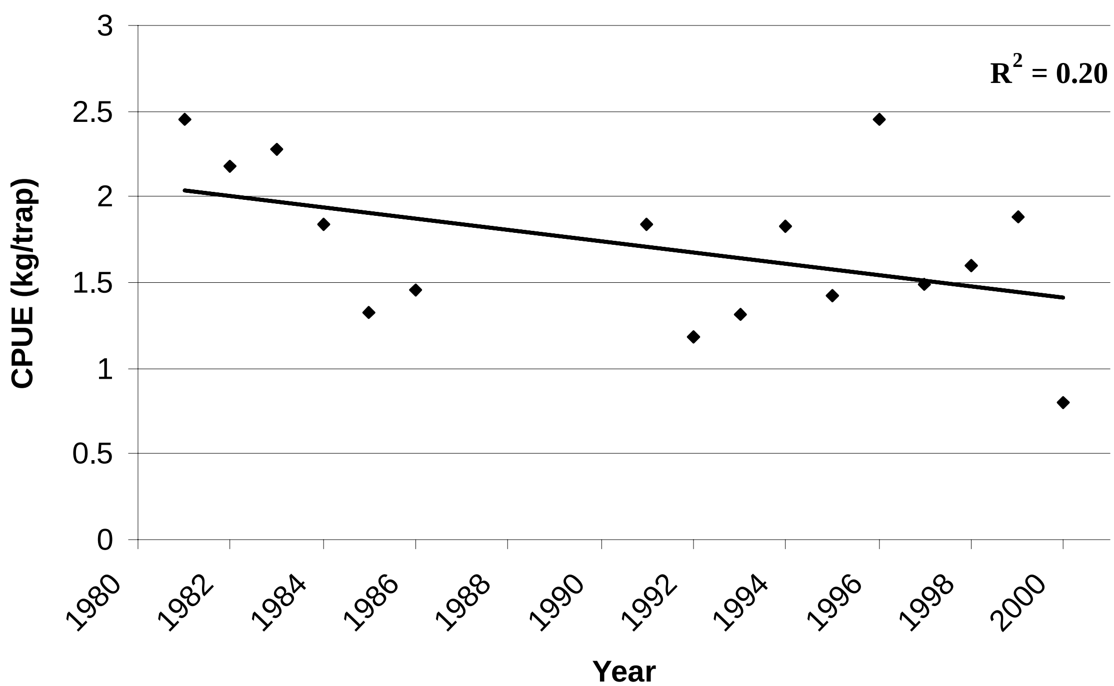


Figure 3: CPUE for the commercial trap fishery, Area 20, 1980-2001. Data were collected from log records.

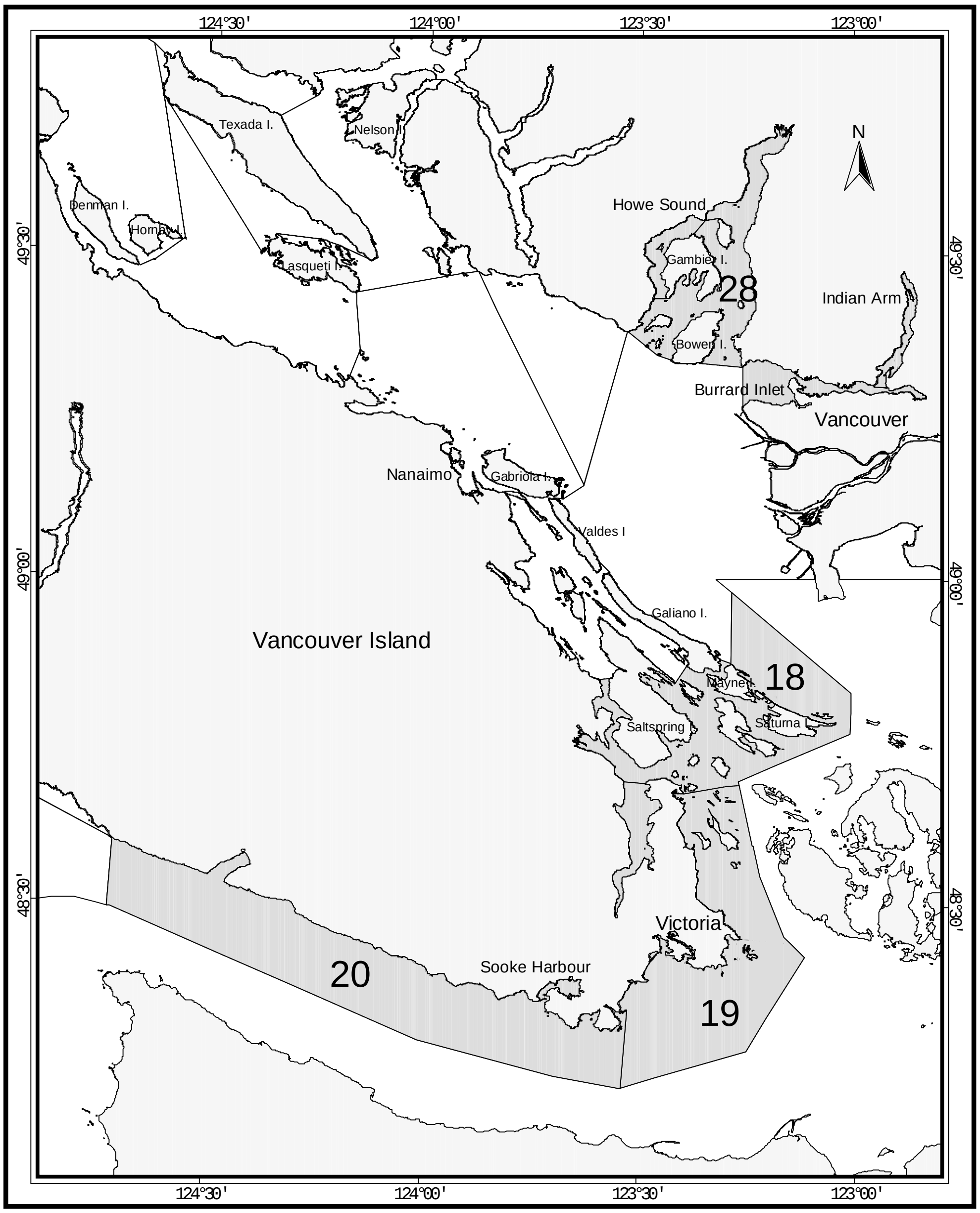


Figure 4: Locations of Areas 18, 19, 20 and 28 in southern British Columbia.

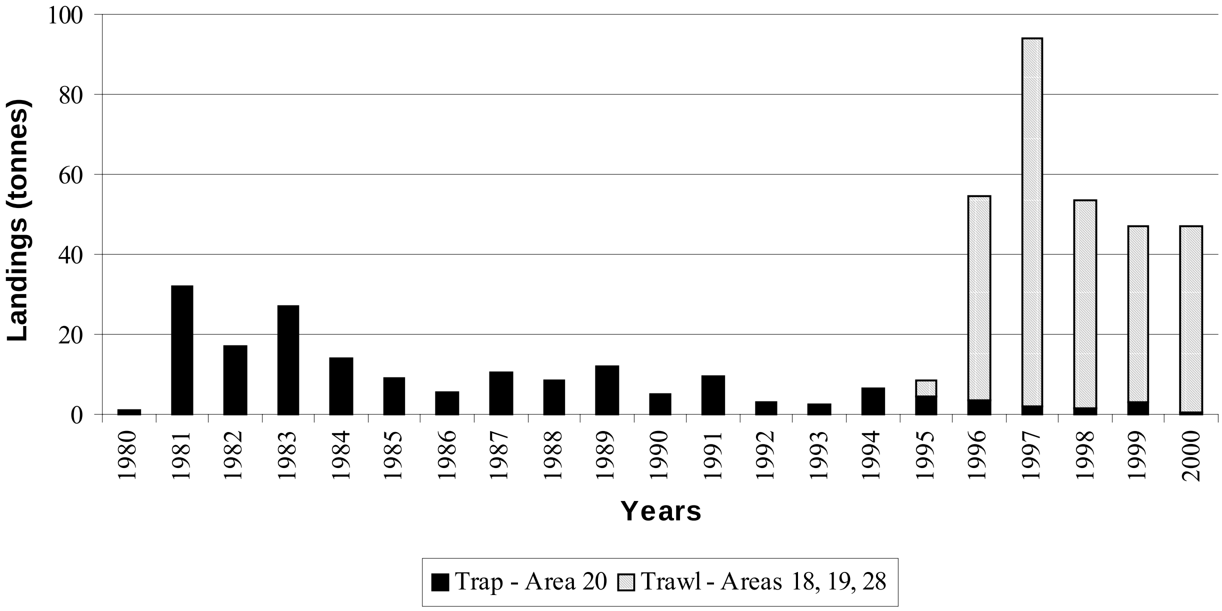


Figure 5: Total landings of coonstripe shrimp by trap and trawl fisheries in Areas 18, 19, 20 and 28, 1980-2000. Note: prior to 1995 in the trawl fishery coonstripe shrimp were not reported separately in logbook records from other shrimp species so these data are not reported here.

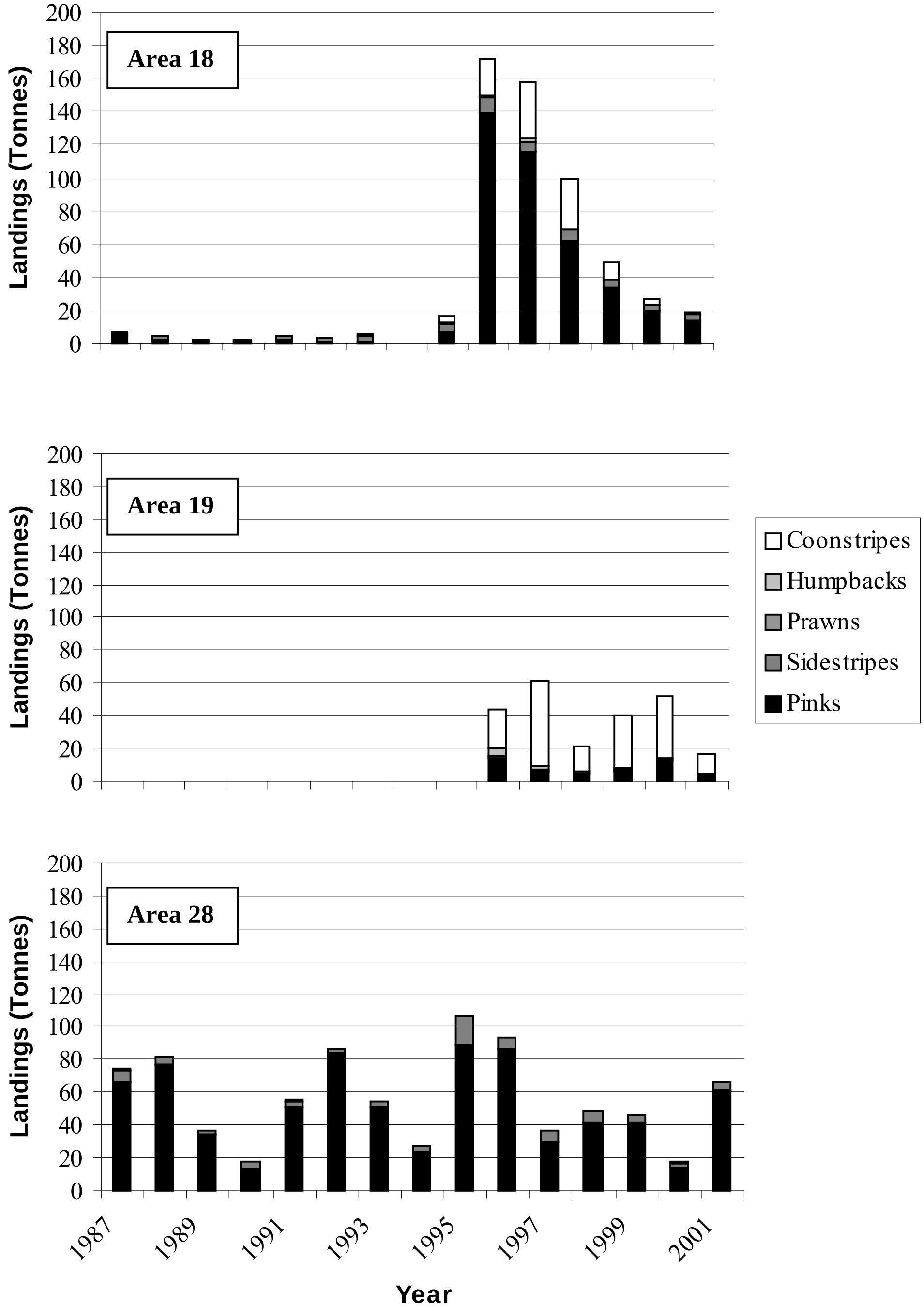
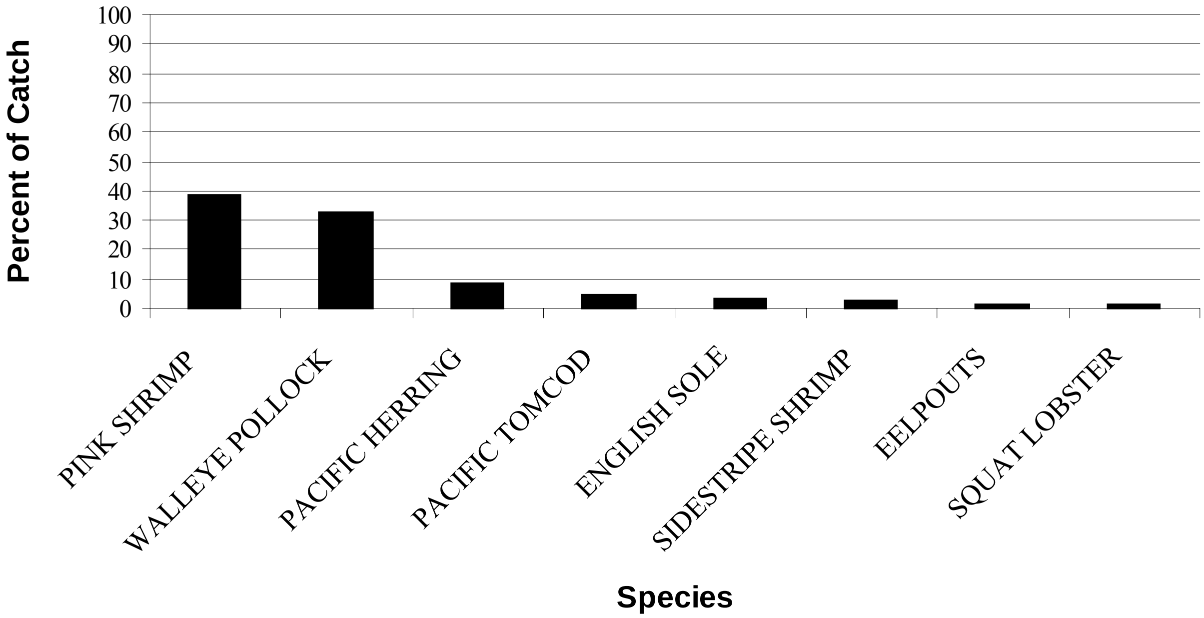


Figure 6: Total landings of all shrimp species by the trawl fishery in Areas 18, 19 and 28, 1987-2001. Data were collected from logbook records.

A) Area 18



B) Area 19

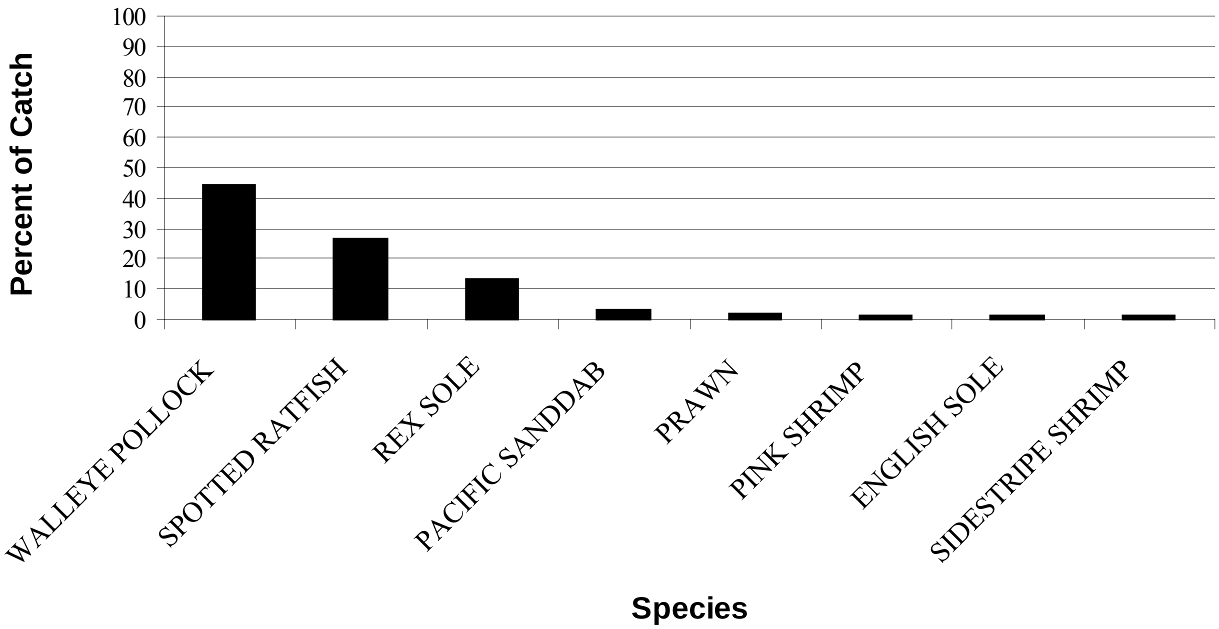


Figure 7a, b: Catch composition of shrimp trawl data from research cruises, Areas 18 and 19, 2000. An extruder was used in Area 18, but not Area 19 trawls. Note: only species that contributed >1% to the total catch are displayed.

Appendix 1

Request for Working Paper – Coonstripe Shrimp Phase 0

Date Submitted: June 26, 2000

Individual or group requesting advice: Fisheries Manager/Biologist, SWG, PSARC, Shrimp by Trawl industry and managers, other stakeholders

Proposed PSARC Presentation Date: November 2001

Title of Paper: *Pandalus danae*, Coonstripe Shrimp: A Review of the Biology and Recommended Assessment Framework for Directed Fisheries

Stock Assessment Authors: J.S. Dunham and J.A. Boutillier

Fisheries Management Reviewers: A. Campbell and K. Barsky

Rational for request:
(What is the issue, what will it address, importance, etc.)

At this time, the harvest of coonstripe shrimp is licensed under both shrimp by trawl and trap licenses and harvest in these fisheries has been generally restricted to an incidental harvest, except for the directed coonstripe trap fishery in Sooke Harbour.

There is growing interest in trawling (beam trawl) in south coast areas (esp. PFMAs 18 and 19) for coonstripe shrimp, as markets for live coonstripe shrimp (particularly after the closure of the prawn fishery) are higher valued than other shrimp. The trawl fishery is involved in partnerships with Fisheries & Oceans and some members would like to explore the economic viability of expansion of coonstripe shrimp harvest.

The current fishery independent area-swept trawl surveys undertaken for the trawl fishery, including trap sampling and biomass estimates, have been made for coonstripe shrimp in Areas 18 and 19. Harvest following surveys has been based on a 33% exploitation rate of the survey biomass estimates. Harvest opportunities have been foregone (1998) in instances where the available quota following a survey is predominantly coonstripe shrimp. Managers require a basis for managing coonstripe shrimp within the current fishery.

There is a need to develop a sound biological basis for the management of the on-going fisheries before these fisheries develop further and the amount of landings and areas fished increase.

Objective of the Working Paper:
(To be developed by FM & StAD)

To review existing literature and fishing practices for coonstripe shrimp (Phase 0 as outlined by Perry (1996)) and to provide a basis for management of coonstripe shrimp within the existing trawl fishery. To explore the possibility for directed coonstripe fisheries.

To outline a Phase 1 management and assessment framework to sample and assess coonstripe stocks in the current trawl fishery and provide management options (may be experimental) to proceed with some specified level of directed harvesting.

Question(s) to be addressed in the Working Paper:
(To be developed by initiator)

Phase 0 as outlined by Perry (1996) for coonstripe shrimp - What is the biology (life history, reproduction, age and growth, trophic relationships, parasites and diseases, population structure and dynamics) of coonstripe shrimp? Are there existing coonstripe shrimp fisheries in B.C. and elsewhere? How are they managed and assessed? What assessment information has been collected from B.C. coonstripe stocks and/or fisheries? Can this information be analyzed? If so, what do analyses show with regards to establishing assessment and management frameworks for coonstripe shrimp?

Phase 1 for coonstripe shrimp - outline for sampling current trawl fisheries and experimental management options to collect information from surveys and fisheries. What are the assessment options from which to base the management of coonstripe shrimp? What are the other assessment and management issues for coonstripe shrimp fisheries? Can a fishery (or experimental fishery) and assessment framework be recommended? If so, what are they? What biological information is required to build the recommended assessment framework and, specifically, what information can Stock Assessment begin to collect?