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A Phase '0' review of the biology and fisheries of the Tanner Crab (*Chionoecetes bairdi)*

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Abstract

The Tanner crab (*Chionoecetes bairdi*) may present some potential as a candidate for a largely inshore developmental trap fishery in British Columbia. Significant fisheries targeting Tanner and related crabs have been carried out in Alaska, Japan and the Canadian Maritimes for some years and considerable information on their biology has been accumulated. This document comprises a review of available information on these crabs in the scientific literature. Biological data identified as relevant to the fishery development process by Perry et al. (1999) are summarized, although it should be noted that these data are largely derived from fished Alaskan stocks which are likely considerably different than BC stocks. Biological and catch data for *C. bairdi* in BC are presented from a number of sources, including exploratory surveys and bycatch data from other fisheries.

Tanner crab fisheries appear to follow a 'typical' pattern of development as production and effort quickly rise through the exploratory phase, followed by cyclic catch variation over a few decades, followed by a dramatic decline in abundance. This is mediated by a number of factors, including possible environmental and natural abundance variations but, in Alaska at least, the end result has been generally characterized as serial depletion of the stocks, as the fishing effort radiates further from fishing ports onto stocks which have not been exploited as a means to maintain high catch levels. Few affected stocks have recovered once so depleted, highlighting the need for caution as the potential for a sustainable fishery is defined.

These crab are widely distributed in BC waters. The data gathered thus far suggest there are significant differences in the biological characteristics of Tanner crab in different areas of BC, supporting the hypothesis that the animals occur primarily as discrete inlet stocks with limited exchange between areas. The information available on the specific biological features of the animals in each area is however limited and data on local abundance(s), growth, maximum size, population structure(s), spatial reproductive scale and continuity, mortality, fecundity, spawning, migration patterns, aggregating behaviours and locations are required.

Preliminary exploratory surveys using standardized Tanner crab pots and survey methods are recommended to determine the distribution, biological characteristics, stock structure and relative abundance between areas. Tagging studies to investigate local movement(s) and growth patterns of the crab are also recommended.

Résumé

Le crabe des neiges du Pacifique (*Chionoecetes bairdi*) peut présenter un certain potentiel comme cible d'une pêche de développement au casier, surtout côtière, en Colombie-Britannique. D'importantes pêches du crabe des neiges du Pacifique et d'espèces apparentées étant effectuées en Alaska, au Japon et dans les provinces Maritimes du Canada depuis plusieurs années, beaucoup de renseignements sur leur biologie ont été recueillis. Le présent document est un bilan des données sur ces crabes présentées dans des ouvrages scientifiques. Les données biologiques identifiées par Perry *et al.* (1999) comme pertinentes au processus de développement de la pêche sont résumées, bien que l'on doit noter qu'elles concernent des stocks exploités de l'Alaska, probablement très différents des stocks de la Colombie-Britannique. Des données biologiques et des données sur les prises de *C. bairdi* recueillies en Colombie-Britannique, issues de diverses sources, y compris des relevés exploratoires et des données sur les prises accessoires récoltées dans le cadre d'autres pêches, sont présentées.

Le développement des pêches du crabe des neiges du Pacifique semble suivre une courbe « typique » : la production et l'effort augmentent rapidement tout au long de la phase de pêche exploratoire, puis les prises varient de façon cyclique pendant quelques décennies et enfin l'abondance fléchit de façon spectaculaire. Le tout est modulé par un certain nombre de facteurs, y compris des variations possibles de l'abondance naturelle et des conditions environnementales mais, en Alaska du moins, il en résulte en général un appauvrissement graduel des stocks au fur et à mesure que l'effort de pêche rayonne de plus en plus loin des ports de pêche sur les stocks jusque là inexploités de sorte à maintenir les prises à des niveaux élevés. Peu des stocks affectés se sont rétablis une fois décimés à ce point, ce qui fait valoir le besoin de faire preuve de prudence le moment venu de définir le potentiel d'une pêche durable.

Le crabe des neiges du Pacifique est très répandu dans les eaux de la Colombie-Britannique. Les données recueillies jusqu'à maintenant donnent à penser que les caractéristiques biologiques de l'espèce varient fortement d'un endroit à l'autre, ce qui étaye l'hypothèse selon laquelle elle se manifeste surtout sous la forme de stocks homogènes dans les inlets et qu'il y a peu d'échange entre ces endroits. Les données disponibles sur les caractéristiques biologiques particulières des crabes de chaque région étant toutefois restreintes, des données sur l'abondance locale, la croissance, la taille maximum, la structure des populations, la reproduction et la continuité à l'échelle spatiale, la mortalité, la fécondité, la ponte, les habitudes migratoires et les comportements et les lieux de rassemblement sont requises.

Nous recommandons d'effectuer des relevés exploratoires préliminaires faisant appel à des méthodes de relevés et des casiers à crabe des neiges du Pacifique normalisés afin d'établir sa distribution, ses caractéristiques biologiques, la structure des stocks et son abondance relative, ainsi que des études d'étiquetage visant à établir les régimes locaux de déplacement et de croissance de l'espèce.

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1.0 Introduction

The Oweekeno First Nation has inhabited the shores of Rivers Inlet on the Central Coast of British Columbia for many generations and is seeking to develop opportunities that fit in with both their traditions and the modern requirements of today's market economy. The need to develop available economic resources in these areas has never been greater and many groups along the coast, including the Oweekeno Nation, are pursuing initiatives to establish locally controlled economic activities which can provide jobs and bolster a new social dynamic for the benefit of their communities. The development of local seafood production capabilities is seen as a potentially economically viable and environmentally rational enterprise for this area.

Developing new fisheries resources in these areas will, by necessity, entail moving into new species, which are currently either underutilized or not utilized at all. Growing awareness of the need to obtain relevant biological information on prospective target species prior to the initiation of a commercial fishery has led to the adoption by Fisheries and Oceans Canada (DFO) of a phased approach to control the development process to ensure that any eventual commercial activity is biologically sustainable. In the past a typical fishery development scenario has seen effort and catch increase over time, as experience and profits in the fishery accumulate, despite declining Catch per Unit Effort (CPUE) as the virgin stock is fished down (Perry et al. 1999). The expectation of increasing profit has in many cases lead to over-capitalization, over-fishing and eventual collapse of the stock as a commercially interesting, if not a biologically viable, resource.

Many hardships arise in the fishing industry when the resources are depleted. The application of responsible and precautionary management policies to ensure an appropriate scale of development is essential to avoid the social and economic turmoil associated with a stock collapse. Scientific advice developed from relevant biological data is essential to this process. Unfortunately, because the volume of data available on any particular fisheries resource is often directly related to the harvest activity directed at the resource (Colgate 1982), the biological information available on underutilized species is inadequate to responsibly manage a fishery. Acknowledgement of the data poor nature of most new fisheries has lead to the implementation of a phased and scientifically defensible approach to the development of new fisheries by DFO.

The approach acknowledges the requirements for a precautionary approach, in that fisheries' systems are only slowly reversible, poorly controllable and subject to considerable uncertainty (FAO 1995), and bases the management strategies and limits on the best information available at any stage. The process allows refinements to the management of the fishery as it unfolds and is designed to progressively accumulate, analyze and interpret data obtained at each of three phases, designated and described as Phases 0, 1 and 2 (Perry et al. 1999).

This report comprises an initial Phase 0 literature review to collect and summarize existing information pertinent to the precautionary development of a new fishery targeting the Tanner crab (*Chionoecetes bairdi*) (Figure 1) in BC.

2.0 Biology

2.1 General Description

Tanner crabs are large Spider crabs, which occur in most marine habitats throughout the world. Crabs are members of the Phylum Arthropoda; Subphylum Crustacea; Class Malacostraca; Subclass Eucarida; and Order Decapoda. Crabs are further subdivided in to two major Infraorders the Brachyura and Anomura (Kozloff 1996), which are distinguished by the former having four pairs of walking legs and the later having three. Tanner crabs are Brachyuran crab of the family Majidae, and genus *Chionoecetes* of which there are three species in BC: *Chionoecetes bairdi* (Tanner crab)*, C. tanneri* (Grooved Tanner crab)*,* and *C. angulatus* (Angle Tanner crab) (Hart 1982). A fourth species, *C. opilio* (Snow crab)*,* is also present in the eastern Pacific but only in the cooler waters of the Bering Sea.

All members of the *Chionoecetes* are closely related and share many morphological, physiological and reproductive features. *Chionoecetes bairdi* is depicted in Figure 2 and is used as a characteristic example of the appearance of the genus. While the species are distinct some degree of hybridization is thought to occur between *C. bairdi* and *C. opilio* in the north Pacific where their ranges overlap (Slizkin 1989) particularly as their mating behaviors are very similar and do not comprise a barrier to interspecific mating (Adams 1982). Merkouris et al. (1998) uses evidence comprising the relatively less complex genetic diversity of snow crab from the North Atlantic coupled with the lack of congeners in that area as evidence that the genus *Chionoecetes* arose in the North Pacific.

2.1.1 Ecological Setting

Crabs are major components of the planktonic and benthic communities of which they are a part at various stages of their lives. They fill a number of functional roles as scavengers, predators and prey. They are opportunistic feeders, taking advantage of seasonal feeding opportunities such as herring spawn in the spring and, possibly, salmon bodies which wash down rivers and creeks into the ocean after their spawning season. They are important predators of a number of different animals including crustaceans, polychaetes, echinoderms and molluscs. As prey, a range of fish, crustaceans and other invertebrates including larger Tanner crab feed upon Tanner crabs.

2.2 Distribution

Chionoecetes spp. occur in the North Pacific Basin extending from the southern perimeter of the Japan Sea, through the Sea of Okhotsk, the Bering Sea, the Gulf of Alaska and down the west coast of North America to at least California (Hart 1982). Species of this genus are found from just below the intertidal (e.g . *C. bairdi, C. opilio*), at least at some times during the year, to depths approaching and perhaps exceeding 3,000 m. (e.g. *C. tanneri, C. angulatus*).

Tanner crabs, *C. bairdi*, are found throughout coastal BC in both coastal inlets and offshore (Figure 3). They have been captured during directed surveys (Jamieson, unpublished data), as incidental catch in surveys for other species (Sloan 1985; Jamieson et al. 1986; Workman unpublished data), during directed commercial trap fishing, as bycatch in trap fisheries for other crab species (Jamieson et al. 1986), during Royal British Columbia Museum collections

(Unpublished data) and have been reported as bycatch in the domestic groundfish trawl fishery (Domestic Groundfish Trawl Observer Database, Groundfish Section, Pacific Biological Station, Nanaimo, BC). The highest reported abundances are from the Portland canal system (Figure 3) in Northern BC where Tanner crab were landed for several years (1981-1983) as by-catch in a directed fishery for golden king crab (*Lithodes aequispina*).

Although juveniles tend to predominate in the shallows, *C. bairdi* of all sizes are found as shallow as 3-4 m at certain times of the year in SE Alaska (T. Koeneman, Personal Communication, Regional Shellfish Biologist, Alaska Department of Fish and Game, Petersburg, AK, 1997). Newly settled juveniles have been found between 298 - 349 m while slightly older crabs with a carapace width (CW) of 6.5 and 12 mm have been found at depths of 18 m and between 55 - 168 m respectively (Slizkin 1989). In SE Alaska Tanner crabs with a CW < 40 mm have been found as deep as 230 m. while adults have been found as deep as 473 m, although the major concentrations generally lie above 300 m.

Zhou and Shirley (1998) found the highest densities of Tanner crab between 140 - 150 m with 9 crabs observed within an 858 m^2 area. The depth distributions of King and Tanner crabs are dome-shaped with the Tanner crabs occurring deeper than red king crabs.

Depth distribution patterns by life history stage for Tanner crab are illustrated in Figure 4. Juvenile males and females are found at similar depths throughout the year until they near the moult to puberty when the distribution patterns diverge. Stevens et al. (1993) observed pubescent female Tanner crabs in shallow inshore waters while mature, multiparous females were generally found in deep waters offshore. As the animals grow, males take up residence over a much wider bathymetric range than females but it appears that the majority of adult (male and female) Tanner crabs migrate to water deeper than 100 m after reaching maturity and mating for the first time. The sexes in *Chionoecetes* species tend to segregate by depth except during the mating season.

2.2.1 Migration

Many crab species, including King, Tanner and Dungeness crabs, are known to undertake seasonal migrations. Adult Tanner crabs do not range widely over their lifetimes but rather appear to migrate back and forth between feeding and mating sites along particular paths determined by gradients in the near-bottom environment (Orensanz et al. 1998). Net yearly horizontal movement for tagged Tanner crab in the eastern Bering Sea averaged 73 km (7 – 87 km) over one year and about 80 km (10 – 359 km) over 2 years, while the average net movement of Snow crab in the same area appeared to be somewhat higher at 79 km/year (11 – 171 km, McBride 1982). In the Gulf of Alaska (Kodiak) mature male Tanner crabs tagged inshore moved into deeper water while mature males tagged offshore tended to remain there and wander randomly within a range of about 24 km (Colgate 1982).

Tanner crabs have seasonal migrations, which are patterned around major life history events including hatching, spawning and moulting. Large male Tanner crab and multiparous females aggregate for larval release and mating, around 150 m depth, in the spring after which they disperse. Smaller mature males and primiparous females aggregate in shallow water for moulting (by the females) and mating after which both sexes disperse to deep water (Stevens et al. 1993; Stone 1999). Stephens et al. (1993) suggest that the majority of the mature male and female

Tanner crabs probably migrate to water deeper than 100 m where they remain for the rest of their lives following their first mating.

2.2.2 Habitat

Local concentrations of Tanner crabs are related to the direction of larval transport by currents, the nature of the bottom and the presence of sufficient foraging areas (Slizkin 1989). The preferred substrates for Tanner crab are green-black mud, fine grey and black sand and shell (Jewett 1982). Juveniles are found on or in these substrates as well as in more cryptic habitats with epiphytic bryozoan and hydroid growths and within dense centres of sponge-like material (Jewett 1982). Zhou and Shirley (1998) reported low densities of Tanner crab in debris habitats.

Adults have been observed partly buried in mud-sand substrates (Jewett 1982), a behavior that is common to many crab species living on soft bottoms. The females are nocturnally active and remain buried in the sediment during daylight hours, presumably as a defense against predators. Once buried only the front of the carapace and the chelapids are visible, supporting the contention that sand-mud bottoms comprise an important habitat. Juveniles of both sexes and mature males are suspected of burying but to what extent is unknown.

2.2.2.1 Oceanographic Effects

One of the defining features of a crab's habitat is the oceanographic environment. Water temperature, salinity, currents and upwelling may all affect the crabs or some other member of the community, at some point in their life with far reaching effects on the dispersal, mortality, growth rates and/or abundance of the animals. *Chionoecetes* crab larvae display some fairly consistent behaviour, such as a preferred depth in the plankton throughout their geographic range, and factors affecting transport, development and settlement of these animals may have somewhat predictable effects.

For example, Zheng and Kruse (2000) report that year class strength in the north and north-western Gulf of Alaska is negatively correlated with increased ocean productivity, as indexed by a deeper Aleutian Low. This is in turn associated with El Nino conditions in the tropical Pacific as well as increased upwelling in the central areas of the Alaska Gyre and increased downwelling along the shore (Freeland 1995). The effect on the crab may be due to increased abundance of some fish stocks, including Pacific Cod (*Gadus macrocephalus*) which are by far the primary crab predator, or it may be due to decreased primary productivity near shore due to increased coastal downwelling.

2.2.2.1.1 Surface Currents

Crab larvae are incapable of significantly affecting the direction and rate of their movement because of their small size and are, as a consequence, at the mercy of currents for their transport to an appropriate settlement area. The effects of water movements on annual reproduction to the juvenile phase are thought to be related to the retention of larvae in an area rather than the absolute rates of larval production (Jamieson, 1986). Evidence of this may be seen in the abundance patterns of SI and SII stage larvae in Cook Inlet in Alaska (Paul 1982) and in Wakasa Bay, Japan (Kon 1982) where the continuing maintenance of higher crab densities is thought to be enhanced by the presence of a surface gyre.

In southeast Alaska population densities of Tanner crabs are lower below 56E 20' N and very little fishing occurs below this latitude. Tim Koeneman (Pers. Comm. 1997) has speculated that the differences in abundance between areas may be the result of different net tidal flows. Net flow north of 56E 20' N is static, moving back and forth, whereas to the south net flow is away from the near shore areas. The reduced net flows to the north may retain and concentrate larvae in these areas. Kon (1982) suggests that the low concentration of larvae observed off the coast of the Tottori Prefecture, in contrast to high densities observed in Wakasa Bay, are caused by similar net flows where larvae are dispersed by a straight flowing coastal current.

2.2.2.1.2 Upwelling

Kon (1982) also reports that enhanced larval concentrations at depths below 50 m in Wakasa Bay, Japan occur in conjunction with a small zone of upwelling. Zones of upwelling are known to affect the distribution of other types of larvae most notably sea urchins which are dispersed by upwelling. In contrast to the positive correlation between upwelling and larval *C. bairdi* abundance, Ebert and Russel (1988) report that "predictable sites of upwelling and locations of cold water plumes - such as capes and headlands - show size frequencies of sea urchins that are indicative of low recruitment rates, while sites without predictable upwelling have size frequencies that indicate substantial recruitment". Upwelling conditions develop along the West Coast during what is known as the Spring Transition Domain, when prevailing winds shift from south-easterly to north-westerly between early February and late April (Thomson et al., 1989).

2.2.2.1.3 Salinity

Live holding experiments with Tanner crabs indicate that they are quite sensitive to decreased salinity and that excessive mortalities will occur within two days if the salinity drops to less than about 25 ppt (Brian Paust, Marine Advisory Program, University of Alaska Fairbanks, Petersburg, Alaska, Personal Communication, 1997). These animals live at depths where changes in the salinity are not pronounced and have a limited capacity to deal with such changes under most circumstances. Of some interest though are the observations of recurrent mass moultings of Tanner crabs in a shallow cove in Alaska (Stone 1999). The salinity at depths less than 20 m are quite variable and the crabs are found between +0.6 - -17.4 m leading to speculation that the crabs may be seeking refuge from predation while they moult or that the lower salinity levels in this environment may provide them with an osmotic advantage during their moult (Stone 1999).

2.3 Reproduction

Spider crabs, like all other crabs, reproduce by sexual means. Sperm are passed from males to females in packages called spermatophores. The spermatophore protects the sperm in stasis until it comes into contact with seawater in the female's body cavity at which point it will break open and release its contents. The female receives and can store the spermatophores in an organ called the spermatotheca, which has the dual role of secretion and storage of sperm.

Fertilization occurs within the female's body cavity after which the eggs are extruded, within 48 hours, onto the female's abdominal flap and attached to the third pleopod. The period since fertilization can be estimated from the egg condition. Newly ovulated eggs are bright orange in color and become darker as they develop. They are subjectively characterized as new when they are yellow-orange and un-eyed and old once they are dark reddish-orange and eyed. Mature females carry eggs throughout the year and egg development generally proceeds on a yearly cycle (ADFG 1985). Hatching occurs in late winter and early spring with the peak hatch out occurring in April to June coincident with the peak of the spring algal bloom (ADFG 1985).

Female Tanner crab must attain morphometric as well as sexual maturity prior to breeding. Females are morphometrically mature when the abdominal flap is wide enough to carry a full clutch of eggs or about the same width as the ventral surface of the crab. Females attain sexual maturity, the production of viable eggs, at the same time as morphometric maturity when they undergo the moult to maturity. Male Tanner crabs mature sexually, or are capable of producing viable sperm, prior to attaining morphometric maturity. Morphometrically mature male Tanner crabs have enlarged chelae which enable them to grasp females for breeding.

Female Tanner crabs can copulate in a soft or hard-shelled condition (Conan et al. 1989) and can fertilize eggs with fresh or stored sperm (A. Paul 1982). The consequences of either strategy are uncertain as the brood size is influenced by both spermatophore source and female fecundity. Assessing the impact of different reproductive strategies by estimating the production of viable eggs is confounded by high egg loss rates and uncertainties surrounding brooding period (Elner and Beninger 1995). A single insemination at the female's moult to maturity is not sufficient to fertilize all subsequent egg clutches (Stevens et al. 1996).

2.3.1 Spawning

Two mating patterns are evident in Tanner crab and result in two overlapping mating periods in winter and early spring in Alaska (Munk et al. 1996). The first involves couplings between soft-shell primiparous females, or females moulting to maturity, and morphometrically mature and immature males right after ecdysis (moulting). This occurs in *C. bairdi* over a six month period extending from January to July in Alaska (Munk et al. 1996). The second type, between morphometrically mature hard shell males and hard shell multiparous females, is limited to a briefer period in the spring shortly after the females release their previous brood (Munk et al. 1996). Egg-hatching occurs in both types of females between January and May (Watanabe 1992).

Breeding for primiparous females involves a migration to shallow water where they form isolated mating pairs at low densities with morphometrically immature and smaller morphometrically mature males. Stevens et al. (1994) hypothesised that primiparous females release large quantities of a pheromone associated with moulting that will attract males from over a large area to ensure mating success. Once in a mating pair, the male holds the female in a pre-copulatory embrace, by grasping the first or second walking leg, until she is ready to moult. When she moults the male turns the female so that their ventral surfaces are in contact. The female then lowers her abdominal flap and the male inserts spermatophores into the spermatotheca (Adams 1982). The male guards the female following insemination to protect his reproductive investment because while she is softshelled other males can remove his spermatophores and replace them with their own. Primiparous females which are not bred within about 1 week of their moult to maturity will not produce usable eggs (ADFG 1985).

Stevens et al. (1996) have observed multiparous female Tanner crabs forming dense mating aggregations on a flat featureless, silt-sand bottom at depths of 150 m in Chiniak Bay annually since 1991. Females will often outnumber the males by 10:1 in peripheral areas, and they are often packed so tightly that their carapaces are touching. Paul and Paul (1996) speculated that this behaviour might reduce the level of fighting between males for mates and save both sexes from unnecessary injury. The core areas of these aggregations are extremely dense with female forming mounds, or pods, up to 1.5 m high, comprised entirely of mature females with eyed embryos. In and around the mounds females may outnumber males by an estimated 100:1. Multiparous females lacking eyed embryos were observed in the areas between mounds and on the periphery where they were occasionally observed in pre-copulatory embraces with large males (Stevens et al. 1996). Once in a pre-copulatory embrace insemination is the same as for primiparous females although the male need not guard a multiparous female for as long following breeding.

Stevens et al. (1996) hypothesized that the multiparous females gather in these aggregations because they do not moult and therefore do not release adequate amounts of a hypothesized pheromone to attract males. The same pheromone associated with moulting is released by hatching embryos so females concentrating their numbers in the process of mound formation might produce cumulative emissions sufficient to attract males. An alternative hypothesis for mound formation is that the elevation off bottom serves as a larval launch pad to release larvae above the benthic surface boundary layer and hastens the larvae's rise to the surface (Dr. Brad Stevens, National Marine Fisheries Service, Kodiak Laboratory, Kodiak, Alaska, Pers. Comm. 2001). The period of fertility for the multiparous females is short in comparison with that of the primiparous females. Primiparous females are fertile for 1 to 28 days following the moult to maturity whereas multiparous females are only fertile for about four days after cleaning their pleopods (Conan et al. 1989). Thus mound formation and the attraction of large numbers of males may ensure mating success for multiparous females participating in the mound.

The size of the male chela is important reproductively because they grasp and hold the female (primiparous or multiparous) in one chela during a pre-copulatory embrace (Donaldson and Adams 1989, Phillips and Lauzier 1997) even as they fend off competition from other males (Paul and Paul 1996). Adult (morphometrically mature) males clasp receptive females more readily and for a more protracted period than juvenile males and are more successful in initiating and maintaining pre-copulatory holds than juveniles. The force developed by the chela is sufficient for clasping in both cases but the output force of the mature male chela is significantly higher, not only because their larger claw provides an increased mechanical advantage, but because they have developed a larger closer muscle (Claxton et al. 1994). Juvenile males on the other hand cannot sustain the hold as easily and the females may wander off more frequently.

Males need not be recognizable as morphometrically mature with large chelae to copulate with primiparous females but must be fully mature and larger than 114 mm CW with both claws intact and present to successfully mate with multiparous females (Paul and Paul 1996b). Small *C. bairdi* males (CW. 70 mm) have been observed mating successfully in the lab but the male crab is always larger than the female in mating pairs (ADFG 1985). Smaller males will attempt to mate with larger females but cannot maintain a hold on the female in preparation for mating or maintain their position in the face of competition from larger males. The sperm from males smaller than 70 mm CW are non-viable in artificial insemination tests (Adams 1982).

The male often passes on a surfeit of spermatophores which the female can store in the spermatotheca until she is ready to fertilize a new batch of eggs if there are no 'adequate' males available from which to obtain fresh sperm (A. Paul 1982). Only spermatophores which do not open and release their contents during insemination are stored in the spermatotheca (Beninger et al. 1993). Sperm vitality, indexed as the proportion of eggs successfully fertilized declines over time, suggesting that sole dependence upon this source of sperm may result in a decreased reproductive capacity for a population (Stevens et al. 1996; Elner and Beninger 1995).

Moriyasu and Benhalima (1998) observed two different morphological spermatophore types in Snow crab: one type with an extremely wrinkled spermatophoric wall was found mainly in adolescent and adult males with a soft or new carapace, while those from hard-shell males had smooth and thin spermatophoric walls. The first type broke open very slowly in the seminal fluid extracted from females whereas the second type rapidly broke open. Further observations of the spermatothecae in females after the mating season revealed that they contained only the wrinkled spermatophores suggest that the smooth, thin walled spermatophores are used for immediate fertilization of oocytes at copulation, while the wrinkled type is stored in the spermatothecae for future fertilization

Larger males receive a larger potential payoff breeding multiparous females because they produce more eggs. The excess spermatophores passed on to multiparous females are also resistant to removal by other males meaning the male does not have to maintain an extended vigil to protect his reproductive investment. A mature male Tanner crab can mate with 8-10 females in a laboratory setting over the course of a breeding season (Zheng and Kruse 1999). This number may decline in the wild because of lower population densities, more discrete distribution of the sexes and/or a more limited mating window.

2.3.2 Fecundity

The fecundity of Tanner crabs increases over their first reproductive year, during their second and declines slightly in succeeding years. The fecundity of female Snow crabs is correlated positively with carapace width and negatively with mean egg diameter (Sainte-Marie 1993). This is however confounded by observations that multiparous females carry up to 43% more embryos than post-extrusion primiparous females of the same size. This is because the fecundity of primiparous females is related to their smaller pre-moult size, whereas that of the multiparous females is related to their present size (Stevens et al. 1993). Another reason for reduced fecundity in primiparous females is that they must partition their surplus energy between moulting and somatic growth in addition to egg production which is the sole requirement for this energy in multiparous females (Paul and Fuji 1989). Eggs of primiparous females are on average 1.4-2.7% larger and they produce from 16.4-22.7% fewer eggs per brood than multiparous females (Sainte-Marie 1993).

Fecundity for female Tanner crabs ranges from 89,000 - 424,000 eggs per brood in the Bering Sea and from 85,000 to 231,000 in the Gulf of Alaska (ADFG 1985) with an overall average production per brood by female of 133,000 (Jewett 1982). A small percentage of adult females, averaging between 2 - 6 %, do not carry egg clutches each year (ADFG 1985). Female Snow crabs in Atlantic Canada produce between 20,000 and 140,000 eggs per brood (Watson, 1969) and between 6,000 and 130,000 in Japanese waters (Ito 1963). Tanner crab eggs increase in size from 0.5 mm to 0.65 mm as they develop from the un-eyed stage to the eyed stage as egg mortality reduces brood size from an average of 234,000 to 151,000 eggs (Watanabe 1992).

2.4 Larvae

Like all crabs, Tanner crabs have planktonic zoea and megalops larvae. The larvae of the different members of the *Chionoecetes* genus are virtually identical except for some subtle differences in abdominal morphology; specialized technical expertise and equipment are required to distinguish between them (Wencker et al. 1982).

Larval release is termed hatchout and is a staged process that occurs over about 30 - 40 days as protozoea break out of their egg cases (Incze et al. 1982). Young, free-swimming planktonic larvae moult 4 times going through a protozoea stage, two zoea stages (SI and SII), and a megalops stage (Figure 5) before they settle to the bottom and take up a benthic existence as fully formed first instar crab. As the embryos hatch out they are termed protozoea, this stage lasts only one or perhaps a few hours. These larvae are negatively buoyant and must swim vigorously to remain suspended in the water. These motions may also trigger, or be otherwise important in, the onset of their first moult to the SI zoeal stage (Incze et al. 1982). The SI larvae are negatively geotactic and swim towards the surface (Yosho et al. 1996). *Chionoecetes* zoea larvae are strong swimmers and are capable of maintaining their position in the face of considerable currents (Incze et al. 1982). Each of the SI and SII zoeal stage lasts about 30 days after which they moult to the megalops stage which may last from 1 to 10 months. Larval periods for snow crab are similar, lasting for a total of four to five months and are comprised of one month for each of the two zoeal stages and two to three months for the megalops stage (Kon 1982). The exact timing of hatchout and the duration of each larval stage is thought to vary in with temperature and feeding conditions with increases in either leading to a shorter intermoult period (Incze et al. 1982).

Hatchout and larval development is species specific in *Chionoecetes*. Large numbers of SI zoea of both *C. bairdi* and *C. opilio* are present in the waters of the SE Bering Sea in April and May each year with peak abundance of *C. opilio* occurring in late April about two weeks earlier than that of *C. bairdi*. The moult to SII in *C. opilio* is well underway by the time the moult starts in *C. bairdi*. The same holds true for the moult to the megalops stage and for the transition to a benthic form. *C. opilio* starts settling out of the plankton in early September while the *C. bairdi* wait until late September through October (Incze et al. 1982).

Like many animals incorporating a larval stage in their lifetimes, the release of the larvae is timed so that adequate feed is available to ensure maximum survival and growth. The release of larvae from Snow crab, *Chionoecetes opilio*, in a sub-arctic fjord is phased with a two to three week lag with the sedimentation peak of phytoplankton particles from the seasonal spring bloom in the upper part of the water column. Senescent cultures of different phytoplankton species induce an increased degree of larval release, in comparison to controls with females exposed to fresh cultures, lending support to the hypothesis that phyto-detritus acts as a chemical cue for initiating and synchronizing reproductive activities in invertebrates living at depths where the light cues are diminished. This may be especially important for populations in high-latitude areas, where the development of plankton communities is highly seasonal (Starr et al. 1994).

The crab zoea feed on a variety of planktonic organisms including diatoms, larval echinoderms, molluscs, worms, fish, and copepods (Warner 1977). Living and moving animal food is required for successful growth and development and must be sized appropriately so the young animals can capture and ingest it. Tanner crab larvae prefer zooplankters, particularly the copepod *Pseudocalanus* in Alaskan waters (Zheng and Kruse 2000).

Animals with an extended larval period often use the larvae as the major agents of dispersal and are able to quickly move into new areas. Dispersal is an important factor in the success of species because of the environmental variability encountered by a stock over the entirety of its range. Unfavourable conditions can exist in parts of their range while optimum conditions prevail in others and the stock can best ensure its survival by being able to take advantage of these differences so that a portion of the young is transported to the different areas. This may be particularly important when local stocks are eliminated because of highly unfavourable events and the area requires re-colonization. Starvation, advection and predation of the larvae are believed to comprise the leading environmental factors affecting year class success in fish (Zheng and Kruse 2000) and by extension, crabs.

2.4.1 Settlement

The megalops larvae settle out and are the first benthic stage in the crab's life-cycle. There may be considerable variation in the length of the period during which the larvae are competent to settle (Incze et al. 1982). This indicates that the larvae are capable of delaying settlement until environmental cues signifying appropriate habitat has been found (Warner 1977). The larvae display a diurnal migration in response to movements of the plankton bloom and may utilize these diurnal migrations to avoid being moved off the continental shelf by tides and currents (ADFG 1985).

The larvae do not show distinct depth stratification by size. Even the distribution of aggregations of like-sized individuals that form once they have metamorphosed into megalopae is patch-like on the substrate, as opposed to banded along depth contours, as they seek particular habitat and substrate type(s) (ADFG 1985). In Tanner crabs, the distribution of the megalopae is similar to that of juveniles with a CW of < 20 mm. The early benthic stage animals occur at depths greater than 50 m and are particularly abundant at depths between 150 - 165 m in the area of Cook Inlet (J. Paul 1982). This contrasts with the preferred settling depth of the Snow crab megalops larvae which are thought to settle out at a depth of about 350 m sometime in mid July off the coast of Central Japan (Kon 1982).

Small *C. bairdi* and Snow crabs (Instars I - V) are cryptic and dependent upon the availability of appropriate substrate (Sainte-Marie et al. 1996) settling out on fine grain sediments with little or no epifaunal shelter (Nizyaev and Fedoseev 1996). The lack of cover reduces the density of predators at the site and the fine sediments provide a suitable substrate for digging into for shelter. This shelter is not particularly reliable and the young crabs are easy prey for sculpins, cod, skates, and flatfish etc. particularly as their carapace is relatively fragile and not equipped with many protective spines (Nizyaev and Fedoseev 1996).

Once juvenile tanner crab settle in an area they remain there until they disperse to deeper water as adolescents (Nizyaev and Fedoseev 1996). The delay between settlement and out-migration results in settling areas becoming increasingly congested as successive cohorts accumulate (Sainte-Marie et al. 1996) making it difficult for later cohorts to access the micro-habitat required to ensure survival due to competition. Intraspecific predation is hypothesised as a mechanism governing cohort strength in Snow Crab populations in the Gulf of St. Lawrence (Lovrich and Sainte-Marie 1997). Older animals dominate juvenile rearing grounds preying on smaller crabs until the moult to maturity at which time they migrate to deeper water permitting a new, dominant cohort to establish itself on the grounds. This produces a cycle of abundance with a period of about 8 years (Sainte-Marie et al. 1996).

2.5 Post-larval Growth

Tanner crabs grow by a series of moults to full sexual maturity following the stages described by Phillips and Lauzier (1997). This pattern is comprised of step-like phases consisting of long intermoult periods, during which the shell is hard, punctuated by periodic moulting periods during which the 'soft shell' animals rapidly expand. Crabs swallow and absorb large amounts of water as a mechanism to increase the volume around which the shell hardens. The excess fluid is gradually replaced by body tissue as the animal fills in (Jamieson and Francis 1986). Feeding rates in *Chionoecetes* spp. increase in new shell crabs and the major period of new tissue growth occurs just after moulting (Jewett and Feder 1982). This mechanism is of interest to fishers because it explains why soft shell crabs have a lower meat yield and a generally softer and a more watery meat texture.

The frequency of moulting is a function of species, water temperature, food availability, body size, sex, and sexual maturity (Jamieson and Francis 1986). The growth patterns of males and females are similar during the juvenile stages but differ after maturity (Watanabe and Maruyama 1999). The growth increment per moult is estimated as an average, expressed as a proportion of the pre-moult size, of about 20% for immature crabs in general, although this is thought to vary somewhat between species. Classification of Tanner crabs sampled off the southern coast of Hokkaido (Table 1) indicate that Tanner crabs attain 33mm CW at instar VIII 1 year after hatching , 71mm CW for instar XI after 2 years and reach adult status at instar XII at 2.5 years (Watanabe and Maruyama 1999).

The increment added on as juvenile males and females moult to an adult stage is similar to those moulting to another juvenile stage (Watanabe and Maruyama 1999). This decreases after puberty in males but thereafter remains more or less constant. The carapace width growth increment recorded for *C. bairdi* averaged 15.1%, over a one year period for animals ranging in initial size of 112 - 163 mm CW. Similar measurements recorded for *C. opilio* ranging in size from 108 - 124 mm CW were 12.9% (McBride 1982).

Moulting of large immature Snow crabs, and possibly *Chionoecetes* spp. in general, is restricted to particular periods during the year and the growth patterns for both sexes of *C. bairdi* are similar during the juvenile stages but change once the animals mature (Watanabe and Maruyama 1999). Munk et al. (1996) report that most male *C. bairdi* from shallow waters in the area of Kodiak Island moult in the fall while females and a minority of males moult in the winter and spring. The timing for females and immature males appears to be centred around the optimum hatching periods for the larvae, which occur during the spring bloom, while the timing of the moult for mature males provides adequate time for hardening of their shells in time for the spring-time mating season.

The largest deviation in growth patterns shows up once full maturity is reached and the females undergo a terminal (final) moult just before they breed for the first time, although they may live for some years afterwards (Paul and Paul 1986). The crabs must grow to a certain size and pass through what is called a "moult to maturity" before they are capable of reproducing. Female gonads mature just before their terminal moult and full functional maturity is reached when the abdomen differentiates to hold the brood at the onset of the moult to maturity (Phillips and Lauzier 1997).

The ovaries of 50% of C. *bairdi* females examined in a survey along the Pacific coast of Northern Japan were orange when they attained 69 mm CW and the onset of maturity was estimated to be 70 and 75mm CW, respectively, for females and males with 50% of the animals reaching full maturity at 84 and 113 mm CW (Watanabe 1992). Studies in the Gulf of Alaska set the size of female Tanner crabs at 50% maturity at about 84 mm CW, reaching about 94 mm CW after the moult to maturity, while males make the transition to their sexually mature form from a slightly larger base of about 90 mm CW (ADFG 1985a). Some reports state that female and male Tanner crabs reach sexual maturity and are capable of mating at about 5 and 6 years respectively (ADFG 1985a) while more recent studies suggest the crabs become sexually mature within 2.5 - 3 years (Watanabe and Maruyama 1999).

The female moult to maturity is generally accepted as a terminal moult (Conan et al. 1989). The female stops growing at this stage although they may live for a number of years afterwards and mate one or more times. Females are termed “primiparous” at this stage and are extremely vulnerable for a period after the moult as their new shell hardens. Females that have reached their terminal moult and have mated at least once are termed “multiparous”. Multiparous females can be distinguished from juvenile and adult males *in situ* by their uniform size, dark shell coloration, relatively short legs and the presence of barnacles and other fouling on the shells (Stevens et al. 1994). The life span of female *C. bairdi* after the terminal moult may extend up to 7 years (Phillips and Lauzier 1997) although the maximum reproductive capacity of females in the eastern Bering Sea is sustained for no more than 5 years (Donaldson and Adams 1989).

Male *C. bairdi* generally grow to a larger size than females, a characteristic that may be explained in part by accumulating evidence that males retain the ability to moult after they have undergone the moult to maturity (Paul and Paul 1996a) although the presence of this in males remains an ongoing subject of debate (Conan et al. 1989; Dawe et al. 1991; Jadamec et al. 1999). On the one hand, the ‘Y’ organ apparently degenerates in mature *Chionoecetes* of both sexes (Conan et al. 1989), a development that is thought to rule out further moults. Evidence to the contrary includes the presence of a second carapace underlying the primary carapace in preparation for moulting in some large, morphometrically mature animals and the observed range of continuing growth (Dawe et al. 1991) which is difficult to reconcile with a terminal moult. For example, large morphometrically mature males have carapace widths of up to 210 mm (T. Koeneman Pers. Comm.1997) while others from the same area apparently stop growing at 110 mm CW.

The relationship between chela (or chelaped) height (CH) and carapace width (CW) of male *Chionoecetes* spp. is used to differentiate the maturity stage of an animal. The defining feature indicating the transition to an adult stage is a definitive increase in the relative size of the chelae to the animal’s carapace so that adult males always have relatively larger claws than juvenile males of the same size. Tanner crab males are categorized as morphometrically mature when their Chela Height/ Carapace Width (CH/CW) are greater than 0.17 and their CH is greater is 17 mm (Paul and Paul 1996a).

One consequence of this pattern is that male crabs cannot be categorized as fully mature on the basis of size alone and juvenile male crabs larger than the minimum legal size may be legally harvested before they can mate efficiently (Comeau and Conan 1992). Male Tanner crabs from the Kodiak area mature sexually at approximately 110 - 115 mm CW and growth at the next moult generally increases their size to 135 - 140 mm CW. This corresponds to the minimum size limit (i.e. 5.5 inches or 140 mm) used in the majority of the Alaskan fishery management areas including the Southeast area (Donaldson and Donaldson 1992).

The terminal moult in male Tanner crabs, if it occurs, is hypothesized to occur several moults after the maturity moult (Conan et al. 1989) but questions regarding what factor(s) determine the size at which the transformation takes place and about how the terminal moult is related to the onset of full functional maturity remain (Yamasaki et al. 1989). Radiographic aging of old shell male carapace suggest that the animals may live up to 7 years beyond their final moult (Nevessi et al. 1996) which, combined with an estimated age of 6 years to the puberal moult (ADFG 1985) plus two additional moults, would translate to a possible maximum age of 15 years, if the inter-moult period is one year, to 17 years if the inter-moult period is two years.

2.5.1 Summary of Tanner Crab Post-larval Growth

As a general summary of this section data for Tanner crab from the northern Gulf of Alaska indicate that:

- Growth per moult among juveniles of each sex is not significantly different and ranges from 25 - 36% for the first through the sixth moults preceding the puberal moult;

- Growth of mature males ranges from 14 - 22% over five moults;

- Size, expressed as Carapace Width (CW), at 50% maturity for females is 83 mm;

- After the moult to maturity, females average 97 mm CW;

- Males experience their puberty moult at 90 mm CW and have an average 112 mm CW once the moult is complete;

- Inter-moult periods gradually increase as the crabs grow so that male crabs measuring less than 35 mm CW moult two or more times per year while crabs larger than 150 mm CW moult only once every 18 months or so;

- Male crabs may have a terminal moult as few males larger than 180 mm CW are caught (Colgate 1982).

- Tanner crab stocks below about 56 degrees N have different growth characteristics than those forming the main fishable stocks in the more northerly waters. The animals are smaller at age and skip moults start at a smaller size (T. Koeneman Pers. Comm. 1997).

- Male Tanner crab of commercial size usually range from 7 to 11 years of age and vary in weight from 1-2 kg;

- The lifespan of Tanner crabs ranges from 14 (ADFG 1994) to possibly 17 years if based on the radiographic ages of very old shell male crabs (Nevessi et al. 1996).

2.6 Recruitment

Recruitment is generally interpreted as a measure of the number of animals reaching the minimum legal size limit for the fishery. As such, recruitment is a function of settlement density combined with the cumulative mortality up to the point of the census (Connell, 1985) although it is often used as a convenient surrogate indicator of the settlement success of a specific cohort. Settlement is often very hard to determine directly because of the depths and small size of the animals involved, and the associated difficulties in achieving a reasonably accurate count.

Recruitment is generally placed among the most important processes affecting the population structure of most species even though the evidence for this is tenuous largely because the periods involved are quite extended. Recruitment of benthic organisms with strong swimming planktonic larvae has three major components: the supply of larvae in the water column, choices made by the larvae at settlement and the survival of the settlers to the time of census (Eggleston and Armstrong 1995). Identifying and assigning some sort of causality to particular factors affecting variation in recruitment is virtually impossible because of the dynamic interplay between them and descriptions of the process remain somewhat subjective and theoretical. For example, most studies which have looked at variations in larval transport and survival - a single component of the process, have not been able to discriminate the effects of spawning population size or density from other factors such as predation levels, larval feeding, plankton biology and physical and chemical oceanographic processes affecting larval abundance patterns (Incze et al. 1987).

Factors affecting recruitment patterns are poorly identified and their relative importance undefined (Harrold and Pearse 1987). Early mortality is considered important in determining future abundance (Sinoda and Kobayashi 1982), largely because of the large number of individuals involved, but little objective data on this dependence is available because of the difficulty in following the planktonic larvae over their extensive larval period. Average survival from hatch out to adult has been estimated at 0.0012% which translates to a mortality of 99.999% with 99% being attributable to the larval stage (Jewett 1982).

Tanner crab recruitment is periodic and highly variable, a situation which produces wide fluctuations in population abundance (Zheng and Kruse 1999). The abundance ratios between the strongest to weakest year classes of Tanner crabs in various areas of Alaska reported by Zheng and Kruse (2000) range from 16 to 113. As a result, the recruitment distributions in crab populations are highly skewed and the populations as a whole are supported by a few strong year classes (Zheng and Kruse 2000). No harvest strategies can prevent stock collapse under these conditions, although more conservative strategies, particularly those which incorporate constant escapement, reduce the probability such an eventuality (Zheng and Kruse 1999).

No direct causal relationship has been established between adult reproductive effort and recruitment success because so little is known of the subsequent variables involved. Larval availability is a function of not only adult reproductive effort but also involves larval mortality and larval transport patterns in an area. The major determinants of availability may well be the currents encountered by the larvae and the local delivery of competent larvae to the area. The effects of these along with the effects of juvenile mortality, disease, environmental variations and various hypothesized effects from other fisheries are impossible to sort out individually and the only conclusions possible at this time involve the cumulative effects observed on the fishable population over time. Different developmental stages have different susceptibilities to the various agents but no definitive accounting of these has been produced and incorporated into a population model to this point.

2.7 Feeding

Crabs in general are opportunistic feeders and will feed on a wide assortment of prey as it becomes available. Tanner crabs appear to congregate in areas with significant food potential and take advantage of events such as seasonal post-spawning die off of herring stocks and concentrations of salmon bodies washing out of streams. Most crabs forage selectively on small-sized molluscan prey well below the critical size that can be opened. The crabs are thought to use this strategy to optimize their energy intake and minimize the risk of claw damage by avoiding attacks on larger, more resistant prey (Seed and Hughes 1995).

Male and female crabs are common in SE Alaska between June and September at 35 - 50 fathoms depth when they may be accessing the higher productivity of nearshore areas. The upper levels have the richest biotic diversity but crabs in areas shallower than 50 m were observed to contain less food than those caught at depths between 125 - 150 m where the diversity is lower (Jewett and Feder 1982). In the SW Gulf of St. Lawrence, adult animals are found at deeper levels where the benthic community is considerably poorer but the authors suggest that the lower abundance of prey is compensated by greater mobility of the crabs (Brethes et al. 1982).

The diets of these animals appear to change over time, presumably in response to changing levels of availability of the various prey items. The diet of Snow crab from the Gulf of St Lawrence in 1991 was dominated by Crustacea (85% of stomachs), followed by Polychaeta (83%) and Mollusca (19%) and the preferences do not appear to vary significantly in crabs of the same size despite apparent environmental disparities (LeFebvre and Brethes 1991). In 1982 the diet was again dominated by the crustaceans but the order changed somewhat with Molluscs (primarily gastropods) being the next most important food item while echinoderms (primarily brittle stars) and polychaetes comprised the third and fourth most abundant components of their diet at depths above 110 m. Brittle stars were the most highly preferred food at all depths in this study and displaced the Crustacea and Mollusca as the most abundant food item at depths below 110 m (Brethes et al. 1982).

The predominant food items also change for Tanner crabs as they grow. Jewett and Feder (1982) report that the food of smaller Tanner crabs (# 40 mm CW) around Kodiak, Alaska included molluscs, fish, decapod crustaceans and polychaetes in decreasing frequency of occurrence. They also found that the preferred prey was at least partially a function of substrate type suggesting that prey availability may be as, or more, significant in determining diet than prey preference. In the NE Gulf of Alaska hermit crabs, barnacles and small clams were identified as important food items in crabs up to 50 mm CW(J. Paul 1982).

For larger Tanner crab arthropods, including shrimps, prawns and crabs, are the dominant food items. These animals are cannibalistic and juveniles comprise the largest single component of the diet of crabs larger than 40 mm CW. Fish and molluscs are second and third while various worms and brittle stars are also found. Fish are consumed once they are killed or damaged by another agent and are probably a prey of opportunity. Barnacles were a significant food item in Cook Inlet but were rarely taken in other areas (Jewett and Feder 1982).

Byers et al. (1984) report the stomach contents of Tanner crab and golden king crab (*Lithodes aequispina*) from Alice Arm and Observatory Inlet on the Northern BC coast. Crabs in Alice Arm fed primarily on Polychaetes, (42 % wet weight, Nephtydae) while those in Observatory Inlet fed primarily on decapod crustaceans, (85 % wet weight, Natantia and Crangonidae). Bivalves (*Transennella tantilla*) were also identified as significant prey items in both inlets but accounted for less than 2 % of the diet by weight.

Like many animals, crabs do not feed at consistent levels throughout the day but are more active at night (LeFebvre and Brethes 1989). The daily feeding rhythms of at least *C. opilio* do not change throughout the life of the animal once it has taken up a benthic lifestyle with the exception of the period leading up to the spawning season when the females apparently stop feeding. Adult Snow crabs will feed opportunistically during the day but feed more actively early in the evening so their stomach fullness peaks around midnight. Even young, newly settled Snow crab are more active during the night (LeFebvre and Brethes 1991) and remain buried in the sediments for most of the day, presumably as a refuge from predation. Another peak in apparent feeding activity appears around dawn although this is not reflected in a peak in the stomach fullness index until about 1100 hrs. (Brethes et al. 1982).

2.8 Mortality

Total mortality (Z) is a measure of the cumulative mortalities from all sources that affect a population and is comprised of natural mortality (M), including such elements as predation, disease and effects on general fitness from competitive interactions as well as fishing mortality (F). The dynamism of the communities involved, the differing sensitivity of various elements of the community to environmental conditions and the cascading effects these differences will have throughout the community means that M is a highly variable element. The mortality rate affecting the population at any time also changes with the particular life history stage under consideration. The current 'virgin' or un-fished status of many Tanner crab stocks in BC may provide the opportunity to determine natural mortality rates for these populations.

2.8.1 Natural Mortality

2.8.1.1 Predation

The vulnerability of these crabs to predators changes throughout the life of the animals. They are most vulnerable during the larval stages when they are at their smallest size. No estimate of the instantaneous larval mortality for these crabs is available in the literature, but applying the lower boundary of the 10 - 20% day^{-1} range suggested for *Mytilus edulis* larvae (Widdows 1991) as a reasonable estimate provides approximately 2,000 survivors from a 200,000 larval brood after 8 weeks for a cumulative mortality rate of 99%.

The larvae need not starve or die in large numbers because of direct temperature or food abundance effects, but these factors cause changes in their development rates and, as a consequence, the amount of time they must spend in the plankton before they are competent to settle out thereby extending their exposure to planktonic predators (Hart and Scheibling, 1988).

Juvenile and adult Tanner crabs are prey for at least seven species of invertebrates, 26 species of fish and four species of marine mammals. The dominant predators are *Chionoecetes* spp.

(including cannibalism), Red King crab *(Paralithodes camtschatica*), skates, eelpouts, Pacific cod (*Gadus macrocephalus*), sculpins (*Myoxocephalus* spp., *Hemilepidotus* spp., *Dasycottus setiger*), Pacific halibut (*Hippoglossus stenolepis*) and Rex sole (*Glyptocephalus zachirus*) (Jewett 1982). Pacific cod are important predators of Tanner crab which are commonly in the top two or three most frequently encountered invertebrate food items in Pacific cod stomach samples (Colgate 1982). Jewett (1982) reports that Pacific cod stomachs contained an average of 3.3 crabs each (maximum = 32) ranging in size from 1.8 to 70 mm CW with about 75% between 7 - 23 mm CW.

2.8.1.2 Diseases

Crabs, like all animals, are subject to a number of diseases and are continuously exposed to bacterial, fungal and viral challenges. These diseases affect the vitality of individuals and populations and can have a strong influence on the marketability of the crab as a fishery product. A number of the more common diseases affecting the Tanner crab stocks in Alaska are discussed below.

2.8.1.2.1 Bitter Crab Disease

An increasing number of crabs infected with a dinoflagellate parasite similar to *Hematodinium perezi* have been identified in the commercial catches of Tanner crab in South-eastern Alaska. This parasite causes a fatal disease in Tanner crabs known as Bitter Crab Disease (BCD) (Love et al. 1993), a chronic wasting disease that causes poor meat quality and 100% mortality in infected crabs. On average about 4% of the Tanner crabs harvested in SE Alaska between 1989 and 1995 were unmarketable because of the disease (Love et al. 1996). This disease remains a concern because its prevalence in Alaska is still increasing and efforts are continuing to better define particulars regarding the life cycle of the parasite, factors contributing to its spread and potential means of control (T. Koeneman Pers. Comm. 1997).

The dinoflagellate causing BCD has been reported as an infective agent in many different decapod species around the world including Scotland (Norway Lobster, *Nephrops norvegicus*), Australia, (Portunid crabs, *Portunis pelagicus* and *Scylla serrata)*, and British Columbia (Spot prawns, *Pandalus platyceros* and Pink shrimp, *Pandalus borealis*) (Love et al. 1996). The disease is quite widespread in Alaska's fisheries, affecting approximately 30 - 40% of the sub-districts in the SE Alaska *C. bairdi* fishery. It was first reported in the Bering Sea Snow crab fishery in 1988 (Meyers et al. 1989) and in the Snow crab fishery along Canada's east coast in 1995 (Taylor and Khan 1995). Recent data (Workman unpub.) confirm the presence of the disease in the deep water Tanner crab, *C. tanneri,* in the offshore waters of British Columbia at a prevalence of 2 to 4 %, studies to confirm the infection rate and species of *Hematodium* sp. are ongoing.

BCD is caused by a dinoflagellate haemolymph (blood) parasite. The presence of the disease is outwardly indicated by a pink carapace and milky haemolymph in the shoulder section. Most mortalities occur during the vegetative phase as the parasites produce metabolites which breakdown the crab's tissue and impart a bitter, aspirin-like flavor to the meat (Meyers et al. 1989).

The disease is apparently cyclical with a vegetative phase from October through July followed by sporulation (production and release of spores) and infection of new hosts. The intensity of the BCD infections increases from January through September when the multinucleate vegetative cells metamorphose into either of the spore types and exit the crab through the gills causing severe 'bleeding' and death. BCD does not apparently affect the general fitness of the Tanner crabs until the spores are released through the gills. This allows the release of the currently held clutches of eggs by the females and suggests that the host-parasite relationship is highly evolved (Love et al. 1996).

The prevalence and intensity of BCD infection were reported by Eaton et al. (1991) to be greatest in the summer, to decline in the fall and winter, and increase again in the spring in Tanner crabs from the area of Sullivan Island in SE Alaska. This agrees with the findings of Love et al. (1993) that the intensity and prevalence of the disease in Auke Bay Tanner crabs increased over the summer May until August and September in both 1989 and 1990 and fell again to zero by mid-winter. This suggests that the level of parasitism apparently increases just after the crabs moult when they have softer, newer shells.

2.8.1.2.2 Black Mat Syndrome

Black Mat Syndrome (BMS) is caused by a marine ascomycete fungus called *Trichomaris invadens*. Tanner crabs with Black Mat Syndrome are unsightly and processors are reluctant to accept infected crabs (Sparks 1982). A pigmented surface encrustation is laid over the shell of the crab while transparent hyphae (fungal 'roots') penetrate the tissues and organs of the infected animal although they have not yet been observed in the heart, hepatopancreas, reproductive organs, antennal gland and brain or thoracic ganglion. The ova (eggs) in heavily infected females, however, are penetrated and die off; removing that animal's reproductive capacity from the population pool.

The invasion of the tissues causes massive destruction in the epidermal and sub-epidermal layers thereby preventing production of replacement cuticle (shell material). This production is necessary for moulting so growth in heavily infected animals is arrested. It is not known if these crabs remain in the population until they are killed off by another agent or if the disease is intrinsically fatal in and of itself. In either case the incidence of this disease may have been a significant factor in stock declines in *C. bairdi* observed in the late 1970's and early 1980's (Sparks 1982).

BMS occurs most frequently in the area of Kodiak and appears to be more frequent in offshore areas compared to inshore bay areas. The syndrome appears most prevalent in females and is higher among oldshell crabs as opposed to newshell crabs. Incidence recorded in male crabs in a study conducted by the Alaska Department of Fish and Game in 1981 varied from a high of 65% in some of the offshore northeastern areas to about 1% in most of the inshore bays around Kodiak and to the SW around the Chignik Peninsula and Western Aleutians. BMS may also infect *C. opilio* and *C. tanneri* stocks in the Bering Sea and Gulf of Alaska but is apparently highly area specific and can be avoided if necessary (Hicks 1982).

2.8.1.2.3 Chitin Digesting Bacteria (Torch)

A chitin digesting bacterium identified as *Photobacterium* sp. has been implicated in a disease of *C. tanneri* from Oregon exhibiting lesions characterized by softening, pitting and blackening of the shell (Grischkowsky, 1982). Tanner crab (*C. bairdi*) populations from Alaska are also susceptible to infection by chitin digesting bacteria, although the particular species was not isolated in 1967 when the disease was first characterized. The disease can be induced in healthy animals through artificial injury or passed from contact with infected shell material. The presence of this infection is indicated by the presence of dark colored shell lesions. Infected animals are in generally poor condition and exhibit low vigor, low meat yield and a soft shell. Poor or no growth results as the infection can eliminate the animal's ability to moult (Grischkowsky, 1982).

2.8.1.2.4 Nemertean worms

Nemertean worms are known to symbiotically infest the eggs of decapod crustaceans and can substantially affect egg survival. These effects may be under-estimated because the mortality effects are not evident in the eggs until they have been infested for a couple of months and most sampling programs coincide with the commercial fishery which occurs early in the brooding season. In the Northern Gulf of Alaska, worms enter the eggs in June and July and depart some months later in the fall after they have killed many of the eggs. Wickham and Kuris (1989) estimate that *C. bairdi* egg mortality attributable to nemertean egg predation is about 35% in the area around Kodiak, Alaska.

Tanner (*C. bairdi*) and Red King (*Paralithodes camtschatica*) crabs are both commonly infected by nemertean species such as *Carcinonemertes regicides* and may act in concert as alternating hosts to the advantage of these egg predators. Both species have relatively long brooding periods (i.e. approximately one year) while the period during which the females are not brooding eggs, and therefore not available as an infection candidate, is only about one month. These periods are not the same in the King and Tanner crabs, generally February to March and April to May respectively, so the optional use of either of these species ensures that hosts are available to provide appropriate habitat to the nemertean worms throughout the year (Wickham and Kuris 1989).

2.8.1.3 Interspecific Competition

There appears to be a kind of feeding hierarchy between different crab species (i.e. *C. bairdi*, King and Dungeness crabs) in SE Alaska (T. Koeneman Pers. Comm. 1997) and the same sort of interplay might become apparent in BC. In Alaska, as in BC, Dungeness crabs generally predominate in the shallows (<20 m), other crab species are not generally found in areas with high abundances of Dungeness crabs. This suggests that the Tanner crabs may be squeezed into particular parts of their preferred habitat and be limited by the abundance of other crabs in the area, with particular reference to the Dungeness crab in BC.

2.8.1.4 Intraspecific Competition

Competition amongst male *C. bairdi* for females is intense. This will often lead to severe injuries or mortality for the males involved or the females under dispute as large, morphometrically mature male Tanner crabs are capable of crushing the carapace and/or perforating the chelae of other males (Paul and Paul 1996).

Tanner crabs are reported to aggregate by size (Nizyaev and Fedoseev 1996) and there are indications that this may be a response, in part, to the known cannibalistic tendencies in these animals (Jewett and Feder 1982). The presence of larger Snow crabs in optimal juvenile habitat forces smaller crabs to more marginal areas (Sainte-Marie et al. 1996) contributing to natural population cycles.

2.8.2 Fishing Mortality

Total fishing mortality comprises the aggregate landed catch, discard mortality in the directed fishery and bycatch mortality in other fisheries (Zheng and Kruse 1999). At the present time, Tanner crab are currently reported as bycatch in only the prawn, (*Pandalus platycerus*) (Jamieson et al, 1986) Dungeness crab, and King crab fisheries, but removals by trawl or other pot fisheries might also be occurring.

Large numbers of females and sub-legal size males are caught in the Alaskan fisheries and returned to the sea. Approximately 5.9 million sub-legal males and 3.6 million females were caught along with the 3.8 million legal sized males harvested in the 1994 Bering Sea Tanner crab fishery for ratios of 1.55:1 and 0.95:1 respectively. There are a number of points where these discard crabs can be injured which can, in turn, lead to immediate or delayed mortalities that they would not otherwise suffer. Broken spines, cracked crushed or punctured carapaces and autotomized limbs are visible but other effects including desiccation and freezing are less obvious (MacIntosh et al. 1996).

These discards are sometimes caught repeatedly during the season and there has been some question about the effects of these recurrent trips up from depths of 70 - 150 m on the condition of the animals. MacIntosh et al. (1996) investigated the effects of this as well as the effects of dropping discarded crabs from a typical 2 m height into the water and found that the effects of either were minimal.

The effects of various fisheries must also be differentiated. Trawl gear causes extensive injuries to the crab while trap fisheries are considered to be much less injurious to the animals, although injury rates of 3-16% and immediate mortality rates of 0.5% have been observed (MacIntosh et al. 1996). In the case of the trawl fisheries, some specialists feel that the number of crabs crushed and killed by trawl gear is 10 to 15 times the actual total reported catch (Thomson 1989).

Female and undersized male Tanner crabs are often caught incidentally during fisheries targeting large males, and can suffer injury or mortality if exposed in air for too long, particularly at sub-zero temperatures. This could become an issue during the winter in many of BC's inlets as outflow winds from the interior of the province can drive temperatures well below 0EC. The effects of air exposure at temperatures above zero appear to be negligible and Tanner crabs have been exposed to levels approaching 240EC-hrs (10EC for 24 hours) with little apparent impact (Carls and O'Clair 1989).

Short term exposure of *C. bairdi* to colder temperatures causes the same degree of damage as a longer exposure to a higher temperature and the damage can be projected as a function of the degree-hours of exposure. This measure is calculated by multiplying the temperature, in EC, by the time of exposure in hours. For example, 30 minutes of exposure at -10EC translates to -5EC-hrs exposure. Mortalities increase significantly below -3 EC-hrs and sub-lethal effects are evident below -2 EC-hrs. Sub-lethal effects include a slowed righting response, autotomy of pereiopods and depressed feeding rates. The righting response is based on the amount of time required by the crab to right itself when placed on its back and is strongly correlated to other delayed responses such as the five day mortality rate and the occurrence of abnormal moulting. The developing larvae on exposed ovigerous females are not apparently affected unless the female dies as a result of the exposure but all expire if she does (Carls and O'Clair 1989).

2.8.2.1 Sensitivity to Other Fishing Operations

Because of the aggregative behavior of Tanner crabs they may be extremely vulnerable to bottom trawls during the spawning-mating period simply because they are so concentrated. A single trawl passing through an aggregation area could completely disrupt the hatching and mating cycle of a large number of animals with associated mortality on the order of 50 - 100% (Stevens et al. 1994). Further details regarding the location, timing and duration of this behavior in the crabs in BC waters is required before any conclusions regarding past and or future impacts, as well as appropriate recommendations for trawling guidelines, can be formulated.

2.9 Biological Summary

The information obtained through this study is summarized in Table 2 according to the requirements laid out in Perry et al. (1999) for a Phase 0 review. This information was obtained from literature sources reporting on the Alaskan and Japanese fisheries and may not apply directly to the *C. bairdi* stocks in British Columbia.

3.0 Harvesting Methods

3.1 General Considerations

The presence of a population of a particular species of *Chionoecetes* crab does not necessarily imply that a viable fishery is possible. A number of extrinsic and intrinsic characteristics affect the economic value of particular species and particular stocks within that species' range. For instance, a number of the stocks are known to be infected to a greater or lesser degree by diseases that reduce the value of the crab as a food product. The amount and quality of meat on the legs also varies between stocks and is a decisive factor in determining the recovery rates from the animals and the economic viability of any fishery targeting the stock. Certain benchmark limits must be attained if the fishery is going to be economically feasible.

3.2 Technologies

Any proposed Tanner crab fishery in BC should be based on a standardized trap technology and design. A number of different pot types were viewed in and around the various plants during an information gathering mission to view the operations of the SE Alaska Tanner crab fishery conducted during the eight day opening between February 15 and 23, 1997. The most common Tanner crab pot is comprised of a conical trap with a base diameter of about 1 to 1.5 m (3 - 4') and a top diameter of about .3 to .6 m (1 – 2'). The crabs enter through a plastic tunnel (~25 cm or 10" diameter) on the upper surface and are unable to climb out. Each trap is usually equipped with two or three 100 to 125 mm (4" to 5") escape rings built into the mesh to allow the escape of juveniles (Figure 6).

4.0 Fishery Performance

4.1 Review of Some Tanner Crab Fisheries

4.1.1 Snow and Tanner Crab Fisheries in the North Pacific Basin

Five species of Tanner crab have been described from the North Pacific region. The geographic and depth ranges of these species are listed in Table 3. The species of interest to Canadian fishers on the Pacific Coast are *Chionoecetes bairdi*, *C. angulatus* and *C. tanneri*. The two species dominating the world Tanner crab market are *C. bairdi,* which is commonly referred to as Tanner Crab, and *C. opilio,* which is known as the Snow Crab.

The Japanese started fishing Snow crabs almost a century ago. These crabs are known as Zuwai crab in Japan and are still harvested in the Japan Sea at depths between 200 and 350 m (Sinoda and Kobayashi 1982). Their operations expanded into the Bering Sea in 1953 where *Chionoecetes* spp. were experimentally fished until 1965 at which point commercial scale operations commenced. This coincided with declining catches and increasing prices for King crabs which increased the market's interest in both Tanner and Snow crab as an alternative. The Japanese catch of *Chionoecetes* spp. in the Bering Sea increased from about 1.5 million crabs in 1964-65 to 12 million animals by 1967-68.

C. bairdi have been harvested commercially in the Northern Gulf of Alaska since 1961 (Jewett and Feder 1982). Operations in the Gulf of Alaska were conducted on a restricted basis by domestic (US) fishers until 1967 largely because the crab fleet was more interested in the abundant King crab resources in that area. The above-mentioned stock decline in the King Crab resource after 1967, however, forced diversification upon the fleet as a means to remain viable and the fleet started to harvest the alternative and more abundant Tanner crab stocks. The catch increased from approximately 54 MT in the 1966-67 seasons to about 1,450 MT and 4,700 MT in 1967-68 and 1968-69 seasons respectively (Figure 7). Production remained at these levels until 1971-72, largely because of poor market conditions resulting from an uneconomical leg-meat extraction process, low consumer acceptance, foreign competition in the limited US market and the presence of an epiphytic fungal encrustation, called Black Mat Syndrome, which further reduced the appeal of the product to the consumer. Directed effort increased as these problems were overcome and catches increased to about 11,000 MT in 1972-73. Production increased further to about 30,000 MT in 1973-74 but fell sharply to about 15,000 MT in 1974-75. Between 1976 and 1980 catches ranged from about 20,000 to 28,000 MT. The 1980 harvest of 20,683 MT was achieved only with a large increase in effort which was motivated by further declines in the Red King Crab fishery. The harvest declined in 1981 to about 13,000 MT (Colgate 1982), and continued to decline throughout the 1980's (Figure 7). By 1990 three of the seven Alaskan management areas in the Gulf of Alaska, Chignik, Prince William Sound and South Peninsula where closed to commercial Tanner crab fishing due to low abundance, these where followed by the closure of Kodiak and Cook Inlet in 1995 the Aleutian islands in 1996 leaving SE Alaska (approximately 1000 MT annually) as the only management area open to commercial Tanner crab fishing in the entire gulf of Alaska until 2000. In 2000 a small 227 MT fishery was permitted in the Kodiak Management area, this continued in 2001 with an additional small, 158 MT fishery in the South Peninsula area.

The tanner crab fishery, including both *C. bairdi* (Tanner crab) and *C. opilio*(Snow crab), is currently the most highly valued invertebrate fishery in Alaska with harvests averaging approximately 99,000 MT annually between 1991 and 1995 (Love et al. 1996). Tanner crabs once dominated the catch but heavy fishing throughout the 1970's and 1980's caused a virtual collapse in these stocks. Snow crab has played an increasingly important role comprising about 90% of the total Alaska catch of these two species by 1989 and increasing to 99 % of the aggregate catch by 1999 (Figure 7). The bulk of the Alaskan catch is landed from large vessels, some up to 200 feet, fishing Snow crab well offshore in the Bering Sea between January and May (Anon 1989).

A small Tanner crab fishery producing approximately 800 -1,500 MT annually since 1970 has developed in SE Alaska and provides the basis for significant economic benefits to the Petersburg and Juneau commercial fishery sector. The fishery in this area is considered local in nature and is not subject to the same fishing pressure exerted in the other areas along the NW margin of the Gulf which are closer to the main fleets in Kodiak and Dutch Harbour. The vessels comprising the Tanner crab fleet fishing in SE Alaska are smaller and more capable of operating in the shallower inshore waters between Petersburg and Juneau. The fishery is conducted over about an 8 day period beginning about February 15 each year (B. Paust Pers. Comm.).

Crustacean fishery resources in the Gulf of Alaska supported some the world's largest commercial fisheries between 1960 and 1980. The Alaskan Tanner and King crab fisheries followed a typical pattern of development which proceeded rapidly from the initial exploration work to very high levels of exploitation. This resulted in production levels that varied cyclically over two to three decades followed by collapse which Zheng and Kruse (2000) suggest that few if any stocks could recover from. Alaskan king crab fisheries collapsed in the early 1980's while Tanner crab collapsed in the early to mid- 1990's.

The decline of these resources follows a pattern that repeats itself over all spatial scales, a pattern referred to as serial depletion of resources (Orensanz et al. 1998). Serial depletion of the Gulf of Alaska crustacean fishery resources was not readily detectable using traditional stock assessment methods which only consider the fates of isolated stocks (individual species in individual areas) but instead, only became apparent as a more generalized event when traditional catch and effort data are aggregated over species, time and space and examined simultaneously (Orensanz et al. 1998). Serial depletion is comprised of two components:

- A spatial component whereby the stocks of a particular species are sequentially eliminated at increasing distances from the fishing center(s). The local stock elimination forces the fishing effort to other stocks further away which are then likewise eradicated.
- The sequential elimination of multiple species when fishing effort moves to new 'less' desirable species as the preferred species is eliminated as a commercially interesting target in a particular area (Orensanz et al. 1998). This is apparent in Alaska through the transfer of effort from King crab to Tanner crab and then ultimately to Snow crab.

4.1.2 Snow crab in the North Atlantic

Snow crab, *C. opilio*, harvests in Eastern Canada started in 1966 in the Gulf of St. Lawrence before extending into Newfoundland in the early 1970's and Cape Breton in 1977. Small to medium sized boats fishing medium sized pots are used in the Canadian fishery in the Maritimes over a season that extends from the spring through the fall (Anon 1989). The stocks are managed by restricting the harvest to males with a carapace width (CW) > 95 mm. The historical landings for Snow crab, or Queen crab, in Atlantic Canada are illustrated in Figure 7.

The establishment of the Atlantic Canada snow crab fishery follows a typical pattern observed in many developmental fisheries. Two periods in the development of the fishery can be identified: the exploratory phase and a period of expansion. Catch level fluctuations during the first phase is thought to reflect the learning process by the fishers as they learn new techniques specific to the new fishery and the discovery of new virgin populations. The expansion phase is marked by increasing recognition of the economic significance of the fishery as increasing effort is applied to the fishery, and catches generally increase (Lamouroux and Lafleur 1982). The catches reached a peak of about 48,000 MT (48 KMT) in 1982 before declining to about 23 KMT in 1989 followed by increases up to about 95 KMT by 1999.

4.2 Potential Stocks in British Columbia

There are three species of Tanner crabs recorded from BC: *Chionoecetes bairdi*, *C. tanneri* and *C. angulatus* (Kozloff 1996). The animals share many characteristics but can be differentiated on the basis of color and depth of capture. An experimental fishery for Deepwater Tanner crab (*Chionoecetes tanner* and *C. angulatusi*) took place off the west coast of Vancouver Island in the late 1980's (Jamieson 1989, Jamieson et al. 1989) but interest faded as world prices for crab declined (Workman et al. in press). However, throughout the 1990s improving markets and local declines of other crab stocks sparked a renewed interest in Deepwater Tanner crab resulting in Phase 0 and Phase 1 assessments (Phillips and Lauzier, 1997; Boutillier at al. 1998), a series of deepwater surveys (Workman et al. 2000; Workman et al. 2001) and an experimental fishery which now harvests up to 100 MT annually off the west coast of Vancouver Island. Commercial concentrations of male *C. tanneri* occur at depths between 580 - 670 m on the continental slope along the BC coast, while adult females lie between 670 - 720 m and juveniles between 720 - 1100 m. *Chionoecetes angulatus* occur at depths below about 1000m off the coast of BC.

C. opilio has not been reported in BC as they occur only in areas where cold water, ranging from - 1.8E to 7.0EC, contacts the sea bed (Slizkin 1989; Jadamec et al. 1999). Adult Snow crab can tolerate temperatures up to about 10EC but the temperature optimum for juvenile development is below zero. *C bairdi*, on the other hand, associates with positive water temperatures at all stages of their life cycle and do occur generally in the coastal waters of BC (Slizkin 1989).

The stock potentials for *C. bairdi* in BC remain poorly defined although there anecdotal reports from fishers which suggest that this crab is quite ubiquitous throughout BC coastal waters. Reports from fishers working in the mainland inlets along the coast north from Queen Charlotte strait up to Portland Canal suggest that there may be substantial stocks available. Exploratory fishing targeting Red and Brown King crabs in and around Portland Canal in 1989 and 1990 failed to produce indications of substantial stocks of King crabs but did indicate the presence of significant numbers of Tanner crab (J Fiddler, Pers. Comm. 1997).

The major sources of information for Tanner crab (*C. bairdi*) in BC include anecdotal reports from fishermen; data collected during DFO surveys of Tanner crab or other species; and bycatch data from several existing trap and trawl fisheries, including shrimp trawl, groundfish trawl, dungeness and king crab trap fisheries and the prawn trap fishery. While these data do provide some indication of the distribution of this species in BC waters (Figure 3) they are insufficient to permit the estimation of abundance or derivation of other population characteristics such as stock structure, growth rates, size at age, fecundity or natural mortality for these crabs in BC. Tanner crab have also been collected and catalogued by the Royal BC Museum from many areas of the BC coast including the North (Portland Inlet, Alice Arm, Chatham Sound), Central (Johnson Channel, Elcho Harbour) and South coast (Satellite Channel, English Bay, Swansen Channel, Quadra Island, Pendrell Sound), off the West Coast of Vancouver Island, off Barclay Sound, in Queen Charlotte Sound and off the west coast of the Queen Charlotte Islands in Tasu Sound (Kerry. Sendall, Collection Manager, Invertebrate Zoology, Ichthyology and Herpetology, Royal British Columbia Museum, Victoria, BC, Pers. Comm. 2000). These collection sites are also indicated in Figure 3.

4.2.1 Data for Tanner crab in British Columbia

4.2.1.1 Sales slip data

Historically the commercial sales slip data base was used to record the landed quantities and values for all species of fish and invertebrates landed in BC. The database was queried for landings of Tanner crab and reported 65 landings between 1988 and 2000 totaling 32,749 pounds. All landings were reported from the north coast in Pacific Fisheries Management Areas (PFMA) 1-6 (Figure 8). Table 4 summarizes Tanner crab landings by year and area, but does not include landings of *C. tanneri,* the deep water Tanner crab. Tanner crab, with few exceptions, was always landed in conjunction with king crab. Red and golden king crabs are permitted species under the conventional "R" crab license. While targeting king crabs in inlets *C. bairdi* is caught as by-catch and until recently has been landed. Prices paid for Tanner crab ranged from $0.50 per pound in 1993 to $3.00 per pound in 1988. The modal price over this period was $2.00 pound.

4.2.1.2 Log Book Data

Fishermen's logbook data are available between 1989 and 2001. Four Fishermen report Tanner crab in their logs exclusively from PFMA 3. The majority of these reports come from two vessels which have actively targeted Red and Golden king crab in PFMA 3 (The Portland Canal System). An additional 18 vessels report King crab on their logs, without reporting Tanner crab, from areas 2, 3, 4, 5, 6, 7, 101, 102, 104, 105, 142, 127 and 19. This might indicate either misreporting of the *C. bairdi* bycatch in the logs and/or an absence of *C. bairdi* in many of the central coast areas.

4.2.1.3 'R' Licence Questionnaire Database

In a recent questionnaire, fishermen were asked to report locations where they have caught *C. bairdi* in the past. They report catches from most areas of the coast with the southern Gulf

Islands, and the mainland and north coast inlets appearing to be centers of abundance. Fishermen report Tanner crab from depths of 6 to 100 m.

4.2.1.4 Surveys

A number of surveys have been conducted by DFO over the last 20 years in which Tanner crab were either the target species or were caught incidentally to the target species. This section provides a brief summary of each of these surveys and the biological data obtained.

In 1982 the M/V Bold Pursuit was chartered to conduct an exploratory survey of golden and red king crab in the Portland Canal System. The purpose of this survey was to assess the viability of a directed fishery. This survey included Portland Canal, Observatory Inlet and the approached to both as well as Chatham Sound and Grenville Channel. During this survey 239 sets were made using Alaskan side entry king crab pots. Approximately 6000 red king crab were caught, 202 golden kings and 1072 Tanner crab of which 1061 were males. Tanner crab catch rates varied from a low of 0 to a high of 15 kg per trap (Jamieson et al. 1986). The size frequency distribution for Tanner crabs caught during the survey is presented in Figure 9. Width Frequency plots were prepared for several of the inlets separately to show the differences in size composition between inlets (Figure 10). These differences in size composition may be indicative of stock differences lending some support the hypothesis that each inlet may be a separate stock.

By 1983 catches of red and golden king crab were declining in the Portland Canal System, including Portland Canal, Hastings Arm, Alice Arm, Observatory inlet, Portland Inlet, Khutzeymateen Inlet and Work Channel. In response, three surveys were conducted in 1983/84 to assess whether the declines were due to fishing pressure or to the discharge of mine tailings from a molybdenum mine in Alice Arm. The surveys were undertaken in Oct.-Nov. 1983, Feb.-Mar. 1984, and July 1984. During these surveys 390 traps were set using both king crab pots and Tanner crab traps (Sloan 1985). In total 3800 Golden King crab, 184 red king crab and 4839 Tanner crab were caught and measured. Mean CPUE for Tanner crab ranged from 0 to 18 crabs per trap depending on depth with highest CPUEs at ~150 m and 300 m (Sloan 1985). Tanner crab traps were shown to be much more efficient at capturing Tanner crab than King crab pots. Width frequency plots by sex for pooled *C. bairdi* data from all three surveys are presented in Figure 11.

A survey to assess the abundance and distribution of *C. bairdi*, *L. aequispina* and *C. tanneri* was conducted between February 28 and March 20, 1984 by the M/V Eastward Ho. The survey was conducted in Queen Charlotte Sound and off the west coast of the Queen Charlotte Islands. 30 sets were completed with a total catch of 23 male *C. tanneri*, 1 female *C. bairdi* and 3 *L. aequispina*. These data tend to support the contention that there are no large untapped stocks of *C. bairdi* in offshore waters. This survey used a combination of top loading Tanner crab traps, side entry king crab pots, Dungeness crab traps and black cod traps.

A Tanner crab test fishery was undertaken between October 2 and 22, 1984. The purpose of the survey was to assess the abundance and distribution of *C. bairdi* in more southerly areas of the coast. Specific areas surveyed included Knight Inlet, Spiller Inlet, Roscoe Inlet, Fisher Channel, Johnson Channel, Dean Channel and North Bentinck Channel, covering management areas 12 and 8. The traps used for this survey were pyramidal top loading Tanner crab traps. During the survey, 63 sets were completed and the catch comprised 830 Tanner crabs, 22 golden king crabs, and 7 box crabs. CPUE by set for Tanner crab ranged from 0 to 5 crabs per trap with an average of 3.5 crabs per trap. Of the 63 sets, 13 had no catch of Tanner crab. Carapace width frequencies for Knights inlet and Dean Channel are presented in Figures 12 and 13 respectively.

Between 1985 and 1999 there appears to have been no directed sampling or survey effort on *C. bairdi*. In a number of recent surveys Tanner crab have been caught as bycatch or through directed efforts and sampled.

A Survey was undertaken in the southern Gulf Islands using conical top loading tanner crab traps in March of 2000. Twenty sets were completed of which 13 yielded Tanner crabs. A total of 420 Tanner crabs were caught. Dungeness and red rock crab were the only by-catch. The CPUE for Tanner crab ranged from 0 to 102 per trap with an average of 20. The width frequency histograms for the majority of the catch obtained on this survey are presented in Figure 14.

During the 2000 CCGS Vector central coast survey (June 26 – July 7, 2000) Tanner crab were caught in Fish Egg Inlet, Dean channel, Emily Carr inlet, Klewnuggit Inlet, and Prince Rupert Harbour. The only location where enough *C. bairdi* were caught to plot a width frequency histogram was Dean Channel (Figure 15). These crabs were quite small, this likely due to the fact that they were caught using Dungeness traps.

Additional Tanner crab data have been collected during annual prawn and crab surveys in Howe sound and Indian Arm. These crabs were caught using prawn or dungeness crab traps and consequently the size composition is of limited value (Figure 16).

One other source of recent Tanner crab data was a Box crab trap evaluation and exploratory survey undertaken in April of 2001. During this survey 40 Tanner crab were caught in the central portion of the Strait of Georgia (MSA 15 and 16). Again these data may be size biased due to gear selectivity but provide useful distributional information. The width frequency plot from this survey is presented in Figure 17. It may also be worth noting that 48%, 12% and 40% were caught above 50m, between 50- 100 m and from 100 - 125 m respectively.

4.2 Fishery Management

Responsible management policy does not strive to simply maximize the yield from fishery resources but also balances other objectives such as the maintenance of size class diversity and sustained and reliable yields (Zheng and Kruse 1999). Minimizing the risks of irreversible damage to reproductive potential of the stock is part of the DFO mandate and remains a paramount consideration.

There is considerable interplay in a number of factors which affect the community structures accommodating these animals. Many of the population models used to provide management guidelines assume that stock replacement, or recruitment rates are steady and a direct function of the animal's abundance in the area. The abundance of the animals, in turn, is a function of its distribution and of the availability of suitable habitats which may or may not coincide with the management area boundaries used. The habitat questions are important because of the effects these animals can have on the community structure, and vice versa. These affect various inter- and intra-specific competitive relationships for the available resources (including food and shelter), the density of predators and the reproductive potential of the stock.

Conservation and rational exploitation of fishery resources is impossible without knowledge of the animal's reproductive patterns, the stocks' reproductive potential and the factors limiting abundance (Nizyaev and Fedoseev 1996). Zheng and Kruse (1999) suggest a management strategy that adjusts legal harvest rates according to changes in stock productivity, as indexed by recruitment strength that allows high legal harvest rates during the upward recruitment cycle and low rates to protect large size crabs and the stock's reproductive potential during the downward recruitment cycle. This requires an estimate of the recruiting biomass, a measure which generally requires fishery independent surveys using, for example: an area swept trawl survey, standardized trap survey, a tagging study or possibly direct visual assessment.

Many benthic marine fisheries are characterized by a lack of life history and biomass data. This is particularly true of new developing fisheries because the accumulation of landings data, a traditional source of stock assessment information, from established fisheries is lacking when the species has not been previously targeted. This picture is complicated by the fact that stocks are hard to assess and they fluctuate for a variety of often unknown reasons. These animals are easy enough to fish with today's modern fishing technology but are notoriously hard to quantify on a regional basis because of their patchy distribution, highly variable recruitment rates and individually variable attraction to the traps.

Uncertainty with regard to the components comprising a stock, compromises the effectiveness of many traditional management tools, including measures such as guideline harvest levels, harvest rates, threshold abundance levels and TACs, which have been used to control recruitment overfishing. Using CPUE alone as an index of abundance is completely unsuitable for spatially structured benthic stocks because of the artificial signals generated when the fishing activity moves to new areas and targets new, previously unexploited stocks making the CPUE appear stable as stocks are depleted at ever increasing distances from fishing ports. The Alaskan experience managing crustacean fisheries clearly demonstrates that once the CPUE drops on a fishery-wide basis, over-harvesting has already occurred (Orensanz et al. 1998), and it may take years or perhaps decades to recover.

Minimum size limits are normally set above the size at which the animal attains sexual maturity as a measure to protect the reproductive potential of breeding stocks in many fisheries. This theoretically increases the effective yield of the resource but environmental factors, including water temperature, habitat, bottom type, food, predation and possibly seasonal trends in the intensity of disease and parasitism and associated mortalities, can play a much more important role in determining the sustained yield than the regulatory regime employed (Donaldson and Donaldson 1992; Love et al. 1993).

There is some controversy amongst scientists and managers with regard to the use of minimum carapace width as the means to limit the harvest of males that have yet to procreate. This may not be the most appropriate definition for ensuring that fishing effort is concentrated on morphometrically mature males because the animals apparently achieve fully functional maturity over a wide range of carapace widths. A change in the relationship between various chelae carapace dimensions is reportedly a more reliable indicator of sexual maturity as the claw enlarges significantly once morphometric maturity is achieved. A ring gauge, sized so that a mature claw cannot pass, could be used to determine the legality of the animal (Jamieson 1989).

Assumptions regarding the sufficiency of male escapement in male-only crab fisheries as a means to ensure maintenance of the reproductive capacity of crab stocks, are increasingly tenuous as new insights into the complexities of male mating behaviours, limits to effective male polygyny and declining viability of stored sperm over time are incorporated into our general understanding of the animals (Orensanz et al. 1998).

The common feature of fisheries that have been successful over the long term is the presence of a large scale refuge for a substantial segment of the spawning population (Orensanz et al. 1998). It would seem that a rational management regime would logically require some provision for reproductive refugia that are held off limits to fishing operations through regulation and enforcement. The criterion for the designation of these areas requires local knowledge of current patterns and larval transport characteristics as well as the spatial distribution of spawners and feeders in relation to the refugia (Orensanz et al. 1998).

4.3 Differences in Fisheries Management Approaches

Scientists may recognize problems in a fishery resource but their ability to remedy them is limited at best (Ludwig et al. 1993). One contributing element may be an inability to incorporate factors involving human motivation and response, which must be considered as an integral part of the system being managed if management is to have a significant degree of effectiveness. The human harvesters should possibly even be considered an integral element of the community in question because of the functional impacts of the harvest activities.

Effective fisheries management requires, at the very least, an understanding of changes in industry behaviour and market responses to management induced stock effects in addition to the more conventionally acknowledged needs for information on the fishery biology and population dynamics of the target species. The premise of this argument revolves around the notion that harvest restrictions affect the supply and demand curve and may, therefore have a cascading effect on the market (Matulich 1989). This supports the contention that economics as well as conservation are elements of the sustainability equation. Conservation work worldwide has shown that there is interdependence between these two factors such that they are mutually reinforcing and neither condition can persist without the other.

The complexity of biological communities and the interactions between species comprising them is such that even detailed prescriptions for the management of individual species within the group are not likely to assure predictability of the stock over the long term. Many factors affecting marine ecosystems, and fishery productivity, are not fully understood but may be critical keys to long term sustainability. Current management guidelines in Canada acknowledge the need to increase the flow of relevant data from, and about, the various fisheries under the DFO's jurisdiction.

4.3.1 Snow Crab Management in Atlantic Canada

This section summarizes the relationship(s) between fisheries management and industry in Atlantic Canada, Alaska and Japan. A more detailed review of the *C. bairdi* and Snow crab management measures taken in the first two jurisdictions is presented in Phillips and Lauzier (1997) and will not be addressed more fully in this document. The East Coast Snow crab fisheries have experienced stock increases and declines similar to those experienced by most fisheries and the resulting socioeconomic consequences have strained relations between industry and DFO. Industry and DFO adopted a more cooperative relationship as a result of a stock decline in the late 1980's and the stock has since been recovering steadily. Factors contributing to this include:

i. a recruitment pulse of small-sized crab occurred in 1988-1989;

ii. substantial advances in the understanding of the complex biology of Snow crab and the development of an accurate, reliable stock assessment methodology together have provided consistent, reliable and credible advice for forecasting the amount and geographic distribution of exploitable biomass for the upcoming fishing season;

iii. industry leaders have worked very hard with their Associations to convince fishers that their fishery was in peril and that close cooperation with DFO was the key for the future;

iv. industry and DFO have been working together as partners to develop a management approach based upon scientific advice to climb out of the trough (Loch et al. 1995).

After a drastic decrease of the snow crab catch in the south-western Gulf of St. Lawrence in 1989, Fisheries and Oceans Canada (DFO) established a management plan for rebuilding snow crab stocks. The management plan included effort controls, trap and license limitation, a fixed quota, derived from an area swept trawl survey, and a soft-shell closure that comes into effect when 20% of the catch is soft-shell crab for two consecutive weeks (Hebert et al. 1992). Intensive on-board sampling programs are used to evaluate the weekly percentage of soft shell crab in the catch. Hebert et al. (1992) report on the trends in weekly and seasonal catches of soft shell crab and discuss the impact of this closure on the fishery.

4.3.2 Tanner and Snow Crab Management in Alaska

Alaskan Tanner and snow crab fisheries have been managed using quotas and size-sex-season regulations. Snow and Tanner crab quotas have been determined using a variety of methods including applying an exploitation rate to an area swept trawl survey abundance estimates (Bering Sea snow crab), fishery performance or trends in CPUE (Kodiak Tanner crab), trap survey abundance indices (Southeast Alaska Tanner crab) and cohort analysis. In recent years, more conservative harvest limits have been developed using exploitation rates applied to pre-season abundance estimates and limit reference points that close the fishery at low levels of abundance or apply reduced exploitation rates to the population during periods of stock decline (Zheng and Kruse 2000).

Tanner crabs #138 mm CW are considered sub-legal pre-recruits and when caught in the commercial fishery are counted before being released. These crabs are assumed to recruit into the fishery the following year. A one year time lag between initial indications from the pre-recruit abundance and the commercial catch was noted as the virgin stock was first fished but the abundance of the pre-recruits and the legal sized animals has varied in phase since the adult male abundance was reduced to approximately 10% of the virgin stock level in 1980. The fishery has become more dependent upon annual recruitment since then. The abundance numbers for both sizes of animals showed signs of recovery in 1981 after emergency closure orders were enforced to allow greater carry over of the post-recruits (Hilsinger 1982).

The Alaska Fisheries Management Board (AFMB) creates the regulations that guide the industry and any member of the public or other interested group has the right, if not the obligation, to propose regulations, raise concerns and comment generally on any and all of the regulations adopted. ADFG staff produce studies which are taken under advisement when the AFMB establishes the regulations so that biological bases, such as fishing seasons and size limits, affecting the fisheries are reflected. Many, if not most, of the regulations address more socioeconomic concerns put forward by community groups, fishing groups and other interested parties.

The Fishery Management Plan established for the Tanner Crab fishery has three basic objectives:

1. Minimize fluctuations in stock abundance due to harvest by maintaining the full reproductive potential of the Tanner crab stocks;

2. Prevent industry overcapitalization and minimize the economic distress due to extreme fluctuations in harvest based on naturally fluctuating stock abundance; and

3. Integrate management of Tanner crab stocks with those of other fisheries to maximize the economic returns and minimize adverse impacts on other stocks (Colgate 1982).

The State of Alaska uses its regulatory authority to:

1. Maximize the yield from harvestable surpluses.

2. Maximize the reproductive potential of the Tanner crab stocks by:

    i. imposing seasonal fishing closures that encompass peak moulting, egg hatching and breeding periods;
    ii. prohibiting the harvest of females and maintaining adequate numbers of males to ensure full fertilization of the female population under normal environmental conditions;
    iii. using a minimum size limit of 140 mm CW for the male crabs which ensures that all males have an opportunity to mate at least once as the males are sexually mature at 135 mm CW; and
    iv. restricting the allowable gear types to pots, ring nets and SCUBA to protect and allow the return of non-legal Tanner crab.

3. Seek economic stability for the Tanner crab industry and avoid overcapitalization by regulating the annual harvest to discourage a too rapid expansion of industry's harvesting and processing capabilities until the potential of the resource is better established and by stabilizing the harvest level within the range of natural recruitment fluctuation (Colgate 1982).

4.3.3 Management in Japan

Japan is one of the great fishing nations of the world and has a long and successful history of community based fisheries management in their territorial waters. The inshore coastal fisheries of Japan produce nearly 1/3 of the total national catch, or about 4 million MT, each year representing nearly 50% of the total catch value (Pinkerton and Weinstein, 1995). These fisheries are managed through a unique community-based system that has its origins in feudal times before the dawn of the 19th Century, but which nonetheless incorporates many progressive attributes. The management model used for the inshore fisheries is the leading example of a system based on fully endowed legal rights for the users of the resource over discrete and legally defined areas. This applies particularly to sedentary resources such as sea urchins, bivalves and seaweed, which are inherently easy to manage on a territorial basis.

Under this system, community based cooperatives, termed Fishery Cooperative Associations (FCAs) are at the centre of fisheries management and provide for an unprecedented level of successful self-management. The system advances the cause of stewardship among the fishing community and sustainability of the fishery resources and the communities that depend upon it. The primary objective of the system is to ensure the optimal use of the resources and the provision of equal opportunity for member fishers (Pinkerton and Weinstein, 1995).

The inshore fisheries management system is fully linked, democratic and transparent. There are three levels involved in the management regime:

- Prefectural Fishing Agencies: administrative bodies representing the prefectoral governors which retain the legal authority for inshore resource management. These agencies set the general rules of operation and are obligated to heed the recommendations and plans of the Regulatory Commissions. The respective fishing rights are granted by the prefectoral government through the agency for 10 year terms, again, according to the advice of the Sea Area Regulatory Commission. The Agencies also take the lead in R&D efforts on aquaculture, enhancement and ranching.

- Sea Area Regulatory Commissions: regional regulatory bodies jointly appointed by government and industry for each of the 65 administrative zones in Japanese inshore waters. These agencies prepare coordinated regional management plans and make recommendations concerning rights and licences to the prefectoral governor. Members of these bodies are elected from the fishing community and appointed by the government as experts to conduct public hearings and collect information needed to advise government.

- Fishery Cooperative Associations: FCAs are more than just fishing associations as we know them. They are the sole entities that hold, or can even legally hold, joint fishing rights over prescribed areas. Each FCA holds exclusive rights to the harvest of designated resources, and extensive management responsibilities towards those resources, in a defined territory and is responsible to designate the distribution of those rights to their membership. The transfer of the fishing Rights is under strict legal control and subject to review by the FCA membership to ensure that dominance of the industry by powerful interests is precluded, and that the economic benefits from the fishery accrue largely to the fishing community as opposed to brokers, marketers and/or arbitragers.

In 1990, there were 2,127 FCAs with a collective membership of about 535,000. These FCAs are organized into 43 prefectural associations and are represented through a single national association. Each FCA reviews the Agency's general plans and then formulates a detailed fishing plan for each of the Rights that they own. The FCAs have the most in-depth knowledge of local stocks and conditions, and sometimes enact more stringent regulations than those passed down from above. These plans are ratified by the membership and approved by the prefectoral government.

All of the generalized indices for the fisheries involved indicate that the management system is very successful. All fishers participating in an inshore fishery must be members of an FCA and all are accountable to themselves and each other as their absolute dependence on the resource(s) means they have to live with their management decisions and have only themselves to blame for bad choices. The production levels appear to be sustainable and the economic value of the fisheries is still trending upwards, despite the continued loss of habitat because of industrial expansion and pollution. The industry has managed to keep pace because of the innovative use of aquaculture, ranching and habitat enhancement techniques (Pinkerton and Weinstein, 1995).

4.4 MOU on Developmental Fisheries

The Province of British Columbia and the federal government signed a Memorandum of Understanding for the Development of Underutilised Fisheries on the Pacific Coast of Canada in 1995. This initiative is designed primarily for underutilised wild harvest species but also contains provisions for establishing aquaculture operations on species not currently cultured. The potential benefits of increasing long term yields by optimizing fisheries to the industry itself, to coastal communities and to the Province, are attractive and have generated a willingness to share in the costs of developing the required conventions.

5.0 Resource Assessment and Monitoring

Accurate assessment of the total Tanner crab stock in the Gulf of Alaska remains a major issue facing management biologists involved in the fishery. An accurate assessment for the Tanner crab should include an evaluation of:

- legal sized male crabs available each year to the fishery
- the female portion of the population; and
- the population of pre-recruit males one to several years away from entering the fishery.

The abundance of mature female Tanner crabs has traditionally been a primary criterion for assessing the stock status based on the logical and direct dependance of the brood (cohort) abundance on the number of females available. Mortality of larvae and smaller juveniles is also an important variable affecting the abundance of pre-recruits (Sinoda and Kobayashi 1982) and, therefore, the biomass available for the fishery in the future. Recruitment monitoring is not a simple function related to the abundance of the females in the area, particularly as Tanner crabs do not form well-defined population groups, and there is considerable transfer of larvae between areas (Nizyaev and Fedoseev 1996).

Snow crab fisheries on the East Coast of Canada and the Bristol Bay Tanner crab fisheries present evidence of 8 and 10-18 year cycles respectively with regard to recruitment variation. Effects from exogenous agents, such as predation by cod and sculpins and environmental cycles have all been largely discounted as possible causes (Sainte-Marie et al. 1996). Habitat saturation and cannibalism targeting new settlers, though, have not. Population dynamic theory predicts that density dependent cycles of abundance naturally arise in populations where the abundance of one cohort declines in response to increasing abundance of older age groups. The period of these cycles is about twice the mean age difference of the two groups. In this case the target cohort is 0 years old while the pressuring cohorts range from two to six years old with more pressure coming from the older cohorts (Sainte-Marie et al. 1996).

Zheng and Kruse (1999) modelled the Bristol Bay Tanner crab population and found the yield curve for Tanner crab in Alaska to be only weakly density dependent and relatively insensitive to high harvest rates. The largest mean yield was obtained at harvest rates > 60%, but noted that this and similar scenarios also entailed very large variations in yield and a high probability of fishery closure. Consequently they recommend harvest rates varying between 0 and 20%.

5.1 Fishery Dependent Assessment

One of the most common traditional fishery-dependent measures used to index abundance is Catch Per Unit Effort (CPUE) data (e.g. the number of crabs caught per pot lift as in Alaska (Hilsinger 1982)) gleaned from fishing logs or sales slips. There are however, a number of potential problems with using CPUE as the basis for assessing fisheries since the relationships among CPUE and stock abundance, market conditions, and management practices are not known and confounded by a number of factors. For example, the transfer of effort to new areas which naturally occurs as the fishers try to optimize their fishing can lead to serial depletion(s) even as the apparent CPUE remains high (Orensanz et al. 1998). Another example would be a stable or increasing CPUE that results from the increasing expertise of fishers or improvements in gear instead of a real increase in abundance. Likewise when using trap CPUE as an index of abundance, CPUE may appear stable due to gear saturation and mask real changes in abundance. The reliability of comparisons of CPUE between years is also in doubt given that different conditions and vessels may be involved and the gear configurations may not be the same. CPUE data from established non-quota based fisheries may provide a reasonable estimate of relative abundance, but its reliability is severely compromised by confounding factors when quotas free fishers from competitive pressures and they fish at their own individual pace (Shepard, 1992).

From the standpoint of long-term sustainability, assessing the stock status of Tanner crabs with CPUE alone presents some major interpretation problems. Stock assessments based on CPUE implicitly assume that the catch rate (CPUE) is directly proportional to stock abundance (Hilborn and Walters 1992). Hilborn and Walters (1992) have concluded that this assumption has been false in almost every case where the assumption has been tested, particularly when historical catch data on the fishery are not available.

5.1.2 Index Fishers

Alaskan fishers report that increasing success after the first year of the fishery is expected and that fishing operations will only attain a breakeven state after two to three years. The learning curve experienced by each fisher will of course depend upon his or her previous experience in similar fisheries but their CPUEs should stabilize once they "establish their credentials" in the fishery. It may be possible to track the original participants in a fishery and obtain a fairly consistent CPUE that tracks relative stock abundance. New entrants into a fishery will skew the CPUE and confound the findings and must be allowed time to come up to speed before being included in the stock assessment database.

5.1.4 Size Structure

Accurate information on the biological and ecological characteristics of the target animal is important for proper management of the resource. Growth rates, size at age and size at maturity are important parameters. The first two characteristics can be estimated from an examination of the modal groups appearing size frequency distributions obtained from the catch. Moulting is synchronous and the moult increments fairly uniform making it possible to follow individual cohorts through time as distinct modes in the size composition data, by examining the moult increment and the frequency of moulting, growth and size at age can be determined. Size at maturity is derived from an examination of either the reproductive organs in different sizes of animals or some other secondary sexual characteristic (telson width or chela height in *Chionoecetes* spp.) that is related to functional maturity and determining the proportion of the population that is sexually or functionally mature at a given size.

The size and age composition of unexploited populations is thought to differ significantly from stocks which have been subjected to fishing pressure for some time. The initial stock contains a high proportion of larger, older, mature individuals which have accumulated over time, whereas a fished stock displays a truncated size and age structure due to the removal of larger individuals by the fishery. As the initial population is fished down the fishery becomes increasingly dependant on annual recruitment. The productivity of the fishery consequently becomes increasingly sensitive to variations in year to year recruitment success (Conan et al. 1989).

The effects of intensive exploitation of the SW Gulf of St. Lawrence Snow crab stocks have been observed as changes in the population size structure. Since the fishery matured in about 1977 the average size of the landed animals has decreased significantly. Many of the larger, and therefore older, individuals have been removed from the population and the fishery is now dependent upon recruitment success in any given year (Lamouroux and Lafleur 1982). As a general trend when the average size of the commercial catch, or adult male population, is increasing it indicates an increasing stock size as the population grows faster than it is harvested, conversely, when the mean size of harvested animals decreases stock size is believed to be declining. This pattern has been observed through three cycles of snow crab abundance in the southern Gulf of St. Lawrence where the current abundance is at an all time high.

The documented natural cycling of Snow crab populations means that biological and economic stability cannot be achieved in these fisheries. Historical collapses in the East coast snow crab fishery are no longer attributed solely to over fishing but highlight the need for industry and management to incorporate the cyclic nature of the resource into their utilization strategy. The number, size and quality of males fluctuate over time, and information which can be used to predict the commercial biomass must be collected and used to protect the stocks and optimize the economic returns.

5.2 Fishery Independent Assessment

The development of satisfactory fishery-independent methods for estimating the abundance of benthic marine organisms continues to be a high priority for research (California Sea Grant, 1993). The purpose of these surveys is to assess a population or populations using observations which do not depend on commercial fishing practices. Done consistently, these surveys should be comparable over a wide range of areas and over a number of years. Common sense suggests that high concentrations, which generally occur in a small proportion of the total area, should be studied in detail, because the precision of the largest observations often determines the precision of the total estimate. Accuracy of the estimates in less dense areas is less important because these areas contribute less to the aggregate total (Stolyarenko, 1995) even though they may cover a much larger area.

5.2.1 Remote Sensing

Remote sensing offers a very real and powerful tool for fisheries management. The use of these technologies can provide large scale survey information, particularly with regard to habitat availability that can be used to identify areas of interest where more detailed surveys can be undertaken.

5.2.1.1 Underwater Video

Some king crab boats in SE Alaska are now using Remotely Operated Vehicles (ROVs) or Towed Underwater Vehicles (TUVS) to locate better fishing grounds to gain a competitive advantage over other vessels participating in the fishery. The use of this type of equipment for stock assessment work has been gaining acceptance as biologists seek non-destructive sampling methods to assess severely depleted resources. The primary shortcoming of using underwater video as an assessment tool to determine the abundance of a particular species is the time required to process the video. Identifying and enumerating all the species of interest recorded on tape can take from 2 to 10 times as long as collecting the initial data. Consequently, any assessment program that depends on video data must provide for sufficient resources to process the collected information. Another shortcoming of underwater video is that it is difficult to collect biological data such as size or age from an image although these issues are being addressed by the development of stereoscopic video or fixed width reference lasers that enable the biologist to determine the depth of field, area viewed and the size of objects in the field of view.

5.2.1.2 Sonar-based Bottom Classification Systems

Bottom classification technologies may be useful for assessing and quantifying the habitat used by Tanner crabs. Roxann and Questar Tangent's QTC system are technologies based on SONAR and can be plugged into any modern sounding system employed in today's fishing fleet. These devices are tied into the Global Positioning System (GPS) so that any data collected can be accurately attributed to a particular position with an accuracy of about 10 meters. Differential correction of these signals is possible so the accuracy is brought down to ∀ 2 m. This data could be used in a model to estimate abundance or identify sensitive areas that should be set aside as refugia.

5.2.2 Capture Surveys

Capture surveys are the primary tool for obtaining fishery independent relative abundance estimates and demographic data on many marine fisheries resources. The various capture technologies each have their own strengths and weaknesses and it may be prudent to employ more than one method per survey to sample all possible habitats and life history stages. Pot and trawl surveys are used in Alaska to estimate pre-season crab abundance and set the harvest levels each year. Japanese authorities use gill nets and traps for their sample surveys (Watanabe 1992) because of concerns that the pot surveys alone are not effective in collecting juveniles and females.

In the Bering Sea the number of female snow crab in the commercial pot fishery comprises a primary measure of the reproductive potential of the stock but fishermen report generally low catches of females in the weeks leading up to the breeding season. The proposed explanation is that females are not attracted to the pots during this period because they do not feed for several weeks prior to spawning (Stevens et al. 1996). This raised doubts about the usefulness of pot derived abundance indices alone for assessing the abundance of females and juveniles. Trawl technology offers a reasonable alternative and King and Tanner crab fisheries in the eastern Bering Sea have been assessed using a systematic and swept-area trawl survey, in conjunction with fishery dependant indices, to estimate biomass and assess the resource since 1981(Somerton and Otto 1999).

Population estimates derived from swept area trawl surveys compare well with estimates derived from commercial fishery data and with the expected growth rates of the juvenile animals (Colgate 1982a). It should be pointed out that abundance estimates obtained directly from swept area trawl surveys involve assumptions regarding the sampling efficiency of the trawl (Incze et al. 1987) which must be defined and tested before any absolute deductions can be adduced from the results of such a survey.

In contrast to the findings reported above, Blackburn et al. (1989) report that differences in the effectiveness of swept-area trawl and trap surveys are insignificant and that concerns regarding the limited sampling efficiency of the pot gear, relative to the trawls, on pre-recruit animals are unfounded. The appearance of crabs less than 100 mm CW in either gear type is irregular but usually indicates strong recruitment of that cohort in the near future (Blackburn et al. 1989).
Pot surveys are currently acknowledged as an effective fishery independent assessment tool for Tanner crab although there are a number of assumptions regarding catchability, effective range, and gear saturation which should be defined to ensure the comparability of results.

5.2.4 Tagging Studies

Tagging studies are often employed in growth, survival and migration studies. Crabs are, in general, difficult to tag because of their periodic moults. King crabs have an isthmus of nerve, muscle and connective tissue where the carapace meets the tail section, which provides a solid base for holding tags. Tanner crabs, in contrast, do not have this tissue. Successful tag retention through ecdysis can be achieved by following the method of Taylor (1982) as follows: "Using slight pressure, the carapace was lifted upwards, the needle of the tagging gun was then inserted through the suture line just over the junction of the fourth walking leg, the needle was angled downward obliquely into the muscle of the shoulder and the tag was inserted. The "set" of the tag was tested by a gentle tug". Shell necrosis around the tag's insertion point may develop in warmer water temperatures and confound the results by making the animal more prone to predation and make any subsequent tag recovery impossible (Taylor 1982).

5.2.4.1 PIT Tagging

Newer tagging technologies, such as PIT (Passive Induced Transducer) tags, are ameliorating some of the shortcomings of conventional tags although they are not cheap, particularly when one considers that the recovery rate is somewhere in the neighbourhood of 1%. The cost is about $5.00 per tag and an unspecified amount for the "reader". PIT tags are comprised of a glass ampoule approximately 6- 8 mm in length which can be inserted into the tip of the dactyl so they are retained through the moult. The tag emits a unique electronic signature when it passes through an electromagnetic field generated by the reading device and allows for live capture, measurement and re-release of tagged animals.

5.4.6 Exploratory Fishing

Exploratory fishing protocols can be designed to achieve a number of different objectives. For example fishing can be conducted with express purpose of only identifying areas of high and low abundance. Alternatively, fishing may be conducted to collect biological samples from as many life history stages as possible or from as many habitats as possible. Fishing may also be undertaken to assess the response of the population under investigation to differing levels of exploitation, or the effectiveness of different size limits by imposing these controls in a limited area, and comparing the biological or population characteristics over time as the different areas are fished. One manner in which exploratory fishing protocols are used to estimate abundance is to undertake a depletion experiment, wherein the intention is to fish down a local stock sufficiently to see a significant decline in catch rates (CPUE). These studies assume there is a relationship between CPUE and abundance and that when declining CPUE is plotted as a function of cumulative removals, the removals that correspond to a CPUE of 0 is an estimate of total population size (Hilborn and Walters 1992).

5.3 Growth Monitoring Methods

Crabs do not have structures which are useful for aging because of the moulting process. Crabs do not have hard calcium deposits in their brains (otoliths), for use as balance organs, as do teleost fishes. The ages of crabs are determined from their size and shell condition. By examining width frequency plots over time or by using tagging data, biologists are able to estimate size at instar and intermoult period; this produces an estimate of the average age of a given size of crab. Shell condition indicates how long it has been since the last moult. By knowing how long it takes for a crab to achieve a given instar and how long it has been since the animal last moulted, the absolute age of the crab can be estimated. A grading system has been developed for the classification of the shell (Shell Condition Index) but the methods are somewhat subjective and therefore unreliable, particularly when different observers are conducting the tests (Paul and Paul 1986).

5.3.1 Shell Condition Index

The shell condition assessment methods are made possible through forensic analysis of the changes in the shell after the previous shell is shed. The shell is soft for the first two weeks (condition index # 1) and then hardens up with little other observable wear for the remainder of the first year (condition index # 2). The sternum becomes progressively yellow and increasingly displays brown scratches while the tips of the legs wear down and barnacles settle on the shell after the first year (condition index # 3). These changes become more pronounced and the encrusting organisms reach a larger size as the shell ages past the two year mark (condition index # 4) (Somerton 1982a).

Tanner crabs, including *C. bairdi,* are often encrusted with a variety of epifauna including barnacles and bryozoans (*Alcyonidium* sp.) (Colgate 1982). The growth of these animals on the shell of the crab has been suggested and tested as a means to estimate the intermoult period. The rationale behind this is that the barnacle growth can be estimated each growing season so that size modes develop over the one to four years the barnacles are expected to remain on the crab. The bryozoans grow at a somewhat faster rate and may be useful in fine-tuning the estimate. The encrusting animals are of course shed whenever the crab moults and the relative numbers of the different size modes of barnacles may help elucidate the number of growing seasons between moults and the proportion of the crabs moulting in a given season. (Paul and Paul 1986).

Examination of mouth parts is a standard method for scientists wanting to determine the position of individual male snow crabs in their moult cycle but this is probably too involved for casual field evaluations. Hoenig et al. (1994) showed that a green coloured carapace can be used as a pre-moult indicator for snow crab, while a simpler destructive method involves simply tearing off the carapace and looking for the presence of a second carapace.

Monitoring the number of soft shelled and encrusted crabs in the commercial catch is a useful indicator of the age structure and recruitment trends in a population. An increase in the proportion of new shelled crabs is interpreted as an increase in recruitment whereas a large proportion of old shelled crabs indicates a lack of recruitment. Interpretation of shell condition indices can be confounded by fishermen's behaviour though and if there is a market preference for clean shelled crab, fishermen will be induced to retain and land only new shell crab and discard all old shell crab, this can result in an artificial recruitment signal (Zheng and Kruse 1999). Shell condition indices should therefore be determined by onboard observers from the unsorted catch or determined during fishery independent surveys.

5.3.2 Radiographic Aging

A radiometric technique based on the ratios of naturally occurring ^{228}Thorium/^{228}Radium has been tested as a means of aging *C. bairdi* shells (Nevissi et al. 1996). The method is based on the consistent ratio of the two isotopes in nature. Once they are incorporated into the calcified matrix of the carapace the isotopic ratio changes at a set rate as the radium decays into thorium with a half-life of 5.76 years. Radiometric techniques require considerable investment in equipment and time but are useful for the calibration of more simply obtained age estimators such as the Shell Condition Indices (SCI).

5.4 Clutch Size

The proportion of female crabs with eggs within a population and the average size of the egg clutches are direct indices of spatial and temporal variability of the reproductive potential of crab populations (Orensanz et al. 1998). A reduction in either of these indices logically indicates a reduction in the availability of males and allows the inference of a developing crisis in the stock. This effect was noted in the King crab fisheries of Alaska (Orensanz et al. 1998) but may not be as applicable to Tanner crabs. Female king crabs do not store sperm for future use when they are mated as do female Tanner crabs. Multiparous female Tanner crab have the ability to fertilze at least one subsequent egg clutch with stored sperm, although the clutch may be smaller, before requiring a mate and will only mate with large morphometrically mature males. Primiparous females mate with smaller and or morphometrically immature males. By monitoring the clutch sizes of multiparous and primiparous females it should be possible to detect a decrease in the number of large, mature, hard-shelled males.

6.0 Conclusions

The conclusions developed over the course of this study parallel those expressed by Phillips and Lauzier (1997) in their 'Phase 0' review of the Deepwater Tanner crabs, *C. tanneri* and *C. angulatus*. Little fishing effort has been directed toward *C. bairdi* in BC waters and the presence of near-virgin stocks provides a unique opportunity to study the population and stock dynamics of these animals. It is important to collect detailed biological data for this species prior to initiating experimental fisheries due to the changes in these characteristics that will result from fishing pressure.

The Tanner crab, *Chionoecetes bairdi,* is present in many areas of the BC coast including the Observatory Inlet system north of Prince Rupert, Douglas Channel, Dean Channel, Knight Inlet, the Northern Strait of Georgia, Southern Gulf Islands, Howe Sound and possibly the continental shelf off the West Coast of Vancouver Island and the Queen Charlottes. There is, however, insufficient information at this time to obtain finer scale estimates of their distribution and abundance for use in formulating an assessment. The acquisition of such information is required before the potential for a sustainable commercial fishery can be determined.

Tanner crab in BC appear to occur as discrete inlet stocks in which mixing is limited. This contention is support by the available biological data, which indicate that the stocks sampled to date appear to display different growth characteristics. Additional corroborative data from allozyme or DNA electrophoresis should be developed to confirm stock structure (Bunch et al. 1998).

The populations of Tanner crabs along the outer BC coastline may or may not be contiguous. On one hand, pelagic larvae off the West Coast of Vancouver Island (WCVI) are continuously exposed to currents running up and down the coast. On the other hand, there does not appear to be evidence of a large, reproductively viable population of Tanner crab in offshore areas although a few animals have been collected off the WCVI, in Queen Charlotte Sound and off the West Coast of the Queen Charlottes. *C. bairdi* larvae from inshore larvae sources may only lightly and intermittently colonize these areas.

Existing fisheries in which Tanner crab is a bycatch species include: the king crab trap, prawn trap, shrimp trawl and groundfish trawl fisheries. Total mortalities attributable to these sources must be quantified and incorporated into any assessment of *C. bairdi* in BC.

It should be noted that several of the world's Tanner crab fisheries have collapsed, a point emphasized by Boutillier et al. (1998) in their framework for the development of a commercial fishery for *Chionoecetes tanneri* and *C. angulatus* off the coast of BC. Several explanations have been proposed for the collapse of Tanner crab stocks in the Bering Sea and Gulf of Alaska, including environmental change and diseases, but excessive fishing pressure has been accepted as the leading cause. The use of fishery dependant (CPUE) abundance indices and passive (Size-Sex-Season) controls resulted in near 100% exploitation rates for legal males, while the impact of handling mortality on pre-recruits and females was unknown. The snow crab fishery, which developed in the wake of the Tanner crab fishery collapse, shows signs of being sustainable; likely this is the result of more active assessment (pre-season abundance surveys) and reduced exploitation rates. In Atlantic Canada the snow crab fishery has been through three cycles of increasing and decreasing abundance. Through each declining cycle new assessment tools have been developed and now the fishery in each of the regions is assessed using a suite of tools including pre-fishery trawl surveys, pre-season and in-season trap surveys, commercial CPUE, mean size of the commercial catch, pre-recruit indices from the fishery and surveys, and shell condition indices. Similar assessment tools should be developed at the outset for any new fishery for Tanner crab in BC ensuring that resource status is well known and the consequences of harvest understood prior to initiating a commercial fishery.

6.1 Basic information Requirements

There are a number of basic information requirements, which must be addressed at the early stages of any Tanner crab fishery to ensure effective management policies are developed and applied. As stated by Phillips and Lauzier (1997), "the more extensive our knowledge the sounder the basis for management". A precautionary approach for new and developing fisheries outlined by Perry et al. (1999) uses scientific research initiated at each stage of the fishery to develop and further elaborate on, the management plan to minimize the risks of overexploitation while optimizing the benefits of the fishery. Insufficient information is currently available to determine the abundance, distribution, biologically sensitive areas, local reproductive potential, degree of aggregation, mobility, mortality or potential commercial value of Tanner crab from any area of the BC Coast. This information is fundamental to establishing a realistic management and development plan.

The information needed to support the sustainable development of a *C. bairdi,* Tanner crab, fishery in BC is as identified by Phillips and Lauzier (1997), and includes:

i. Whether the resource comprises a single contiguous stock or a series of isolated populations;

ii. The geographic and bathymetric distribution of the species and the identification of critical habitats, including spawning, moulting, and juvenile rearing areas and any apparent variability in these distributions;

iii. Basic features of the life history of the animals in each area, with particular reference to breeding times, moult periods, seasonal behavior, size at sexual maturity and morphometric maturity, the size range of functionally reproductive adults and period of the reproductive cycle;

iv. Population size and age structure to allow the estimation of life span, growth and mortality rates;

v. An estimate of the natural mortality rate is required for the development of reasonable management strategies using TACs or exploitation rates;

vi. Information on recruitment patterns must be collected from the outset;

vii. The impact of fishing activities on various components of the crab population and the other members of the communities to which they belong including mortalities due to handling, thermal shock, or displacement; and

viii. The effects of fishing on population structures or dynamics including whether any density dependant relationship(s) will be altered with the removal of large, older males.

Natural cycles and environmental variation influence the abundance of crab and there are considerable uncertainties about the population dynamics affecting, and the interactions between, the various stocks of animals making up the community within which these crab exist. The need for additional information on the stocks in each area and for close monitoring of any changes prompted by fishing activity is highlighted by the diversity of the potentially unique inlet, fjord, channel and oceanic habitats where *C. bairdi* is found in BC. The effects of fishing on different stocks can therefore be expected to be at least somewhat unique.

7.0 Recommendations

7.1 General Biological Recommendations

The recommendations arising from this study again parallel those developed by Phillips and Lauzier (1997). It is recommended that harvest criteria for each area (inlet) be developed with reference to the local reproductive biology and may include carapace width, chelae height, intermoult state, moult frequency and female reproductive potential. An additional harvest consideration should be the minimum acceptable market size, given that the available size composition data indicates that some populations may be too small to harvest. General recommendations are outlined below:

i. Extensive surveys using standardized traps are recommended to investigate the following:

   a. Population characteristics such as distribution, abundance, recruitment, stock composition, disease and parasite infection rates, and natural mortality;
   b. Biological characteristics including size, weight, age, growth rate, maturity schedule, migration pattern, spawning season, egg brood duration, moulting period and frequency;
   c. Critical habitats for larval release, larval settlement, juvenile rearing, moulting and feeding;

ii. Biological samples should be collected from all areas surveyed to establish a tissue bank for genetic profiling and stock structure studies;

iii. Tagging studies to evaluate stock structure, population size and seasonal movements should be considered and if possible initiated at an early stage;

iv. Any future commercial activities targeting these crab should:

   a. Use standardized gear;
   b. Be monitored by observers and dockside validation to ensure effective catch monitoring and biological data collection;
   c. Be managed on a small spatial scale until stock unit size and composition can be determined;
   d. Make every effort to minimize discard mortality through the use of passive sorting mechanisms such as escape rings;

v. The eventual establishment of closed reference areas is recommended once appropriately sized and located reserves can be identified during the 'Phase 1 "Fishing for Information" stage. These areas will act as reference (control) areas as the fishery develops and allow retention of the option to rebuild stocks outside these areas should such a capability be required;

vi. Limited experimental fisheries and adaptive management experiments are recommended to establish a CPUE time series and explore population responses to a variety of management strategies. It should be noted that the requirements for each area are likely to be unique and that a generalized solution applicable to all areas (inlets) may prove illusory.

7.2 Specific Data Requirements

Again referencing Phillips and Lauzier (1997), vessel logbooks should be mandatory during all phases of the fishery. The logbooks should contain accurate geo-referencing, depths of gear and information on the gear types used, soak times, trap spacing, bait type and bait load. A record of all traps pulled should include the species composition of the catch, the number of discards by sex, the number of crabs kept and the total weight of landed crabs.

Data collected by the on-board observer should include detailed catch information on all species caught. Specific biological measures for *C. bairdi* should include shell width, chela height, sex, reproductive condition, shell condition (age), an injury evaluation and the incidence of disease or parasites. Other at-sea data might include detailed morphometric measurements, weight, an evaluation of gonadal state and intermoult state via mouthparts.

Laboratory analysis of the collected samples may include morphometric measurement, microscopic evaluation of gonadal condition, estimation of fecundity, precise evaluation of intermoult state and shell age, incidence of disease and infection and other physiological measurements.

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Table 1: Estimated age at moult, life stage and instar of Tanner crabs sampled off Japan (Watanabe and Maruyama 1999)

	Male			**Female**	
	Adult	**Juvenile**		**Juvenile**	**Adult**
Age	**75-148 Avg CW**	**28-134 Avg CW**	**Instar**	**28-98 Avg CW**	**76-114 Avg CW**
1 yr		33	VIII	32.9	
		40.6	IX	40.4	
		52.8	X	52.7	
2 yr		71.3	XI	71.7	
2.5 yr	93.8	92.7	XII	85.6	86.1
	116	116.6	XIII		101.3
	128.5	128.4	XIV		
	141.7		XV		

Table 2: Biological summary for the Tanner crab (C. bairdi) fished in Alaska and/or Japan

Geographic Range:	Pacific coast of North America from Oregon to Alaska Aleutian Peninsula, Bering Sea, Sea of Japan, Okhotsk Sea
Bathymetric range	adults: 10 - 500 m (Slizkin 1989) most common at ~ 150 m in Alaska
Preferred Substrate	green & black mud; fine gray-black sand and shell (Jewett 1982)
Maximum Size:	
Male	210 mm CW (Koeneman, pers comm 1997)
Female	114 + mm CW (Watanabe and Maruyama 1999)
Age at maturity	
Male	6 years (ADFG 1985)
Female	5 years (ADFG 1985)
Size at onset of maturity	
Male	75 mm CW (Watanabe 1992)
Female	70 mm CW (Watanabe 1992)
Size at 50% maturity	
Male	113 mm CW (Watanabe 1992)
Female	84 mm CW (Watanabe 1992)
Size at moult to maturity	
Male	pre-moult: 90 mm CW; post-moult: 114 mm CW (Colgate 1982)
Female	pre-moult: 83 mm CW; post-moult: 97 mm CW (Colgate 1982)
Legal size limit (AK)	140 mm CW: males only- females prohibited
Age at recruitment to fishery	5-7 years: growth rates etc may vary with temperature
Maximum age	
Male	14 years (ADFG 1994); 17 years (ADFG 1985 + Nevessi et al. 1996).
Female	10 years
Fecundity	89,000 - 424,000 eggs per brood in Bering Sea (ADFG 1985)
	85,000 - 231,000 eggs per brood in Gulf of Alaska (ADFG 1985)
Egg Extrusion	January-May (Alaska) (ADFG 1985)
Reproductive cycle	1 year
Spawning migration	spawning aggregations observed at 150 m (Stevens et al. 1996)
Larval period	60 - 66 days (Incze et al. 1982)
Juvenile depth	150-165 m (J Paul 1982);
	75-300 m (Slizkin 1989);
	10-80 m (Stevens et al. 1996).
Fisheries Experiences	Periodic and variable recruitment; widely fluctuating abundance, conservative harvest management strategy does not eliminate and only reduces the probability of collapse. May be best classified as a slowly renewing resource

Table 3: North Pacific *Chionoecetes* spp and their distribution (Colgate 1982)

Species	Depth	Geographic range
Chionoecetes opilio	13 - 400 m	Bering Sea - Arctic - North Atlantic
Chionoecetes opilio elongatus	to 2225 m	Sea of Japan, Okhotsk Sea
Chionoecetes bairdi	5 - 475 m	Bering Sea to Oregon
Chionoecetes tanneri	53 - 1940 m	Bering Sea to Southern California
Chionoecetes angulatus	90 - 2975	Bering Sea to Oregon
Chionoecetes japonicus	410 - 2105	Sea of Japan

Table 4: Reported landings of Tanner crab (*C. bairdi*) on British Columbia's north Coast between 1988 and 2000 from the DFO commercial sales slip database. Landed weights are in Kilograms, landings represent a single offload at a plant by a single vessel.

Year									
Area		**1988**	**1989**	**1990**	**1992**	**1993**	**1994**	**1997**	**Grand Total**
1	Weight	-	250	-	-	-	-	-	250
	Landings	-	2	-	-	-	-	-	2
2	Weight	10	-	-	-	-	-	-	10
	Landings	1	-	-	-		-	-	1
3	Weight	401	-	3414	4618	121	457	4317	13328
	Landings	3	-	10	12	1	2	11	39
4	Weight	8	95	-	-	-	-	111	214
	Landings	1	2	-	-	-	-	1	4
5	Weight	-	-	-	-	299	-	525	824
	Landings	-	-	-	-	4	-	5	9
6	Weight	32	-	-	-	75	-	129	236
	Landings	2	-	-	-	3	-	4	9
Total by Year	Weight	451	344	3414	4618	495	457	5081	19073
	Landings	7	4	10	12	8	2	21	73

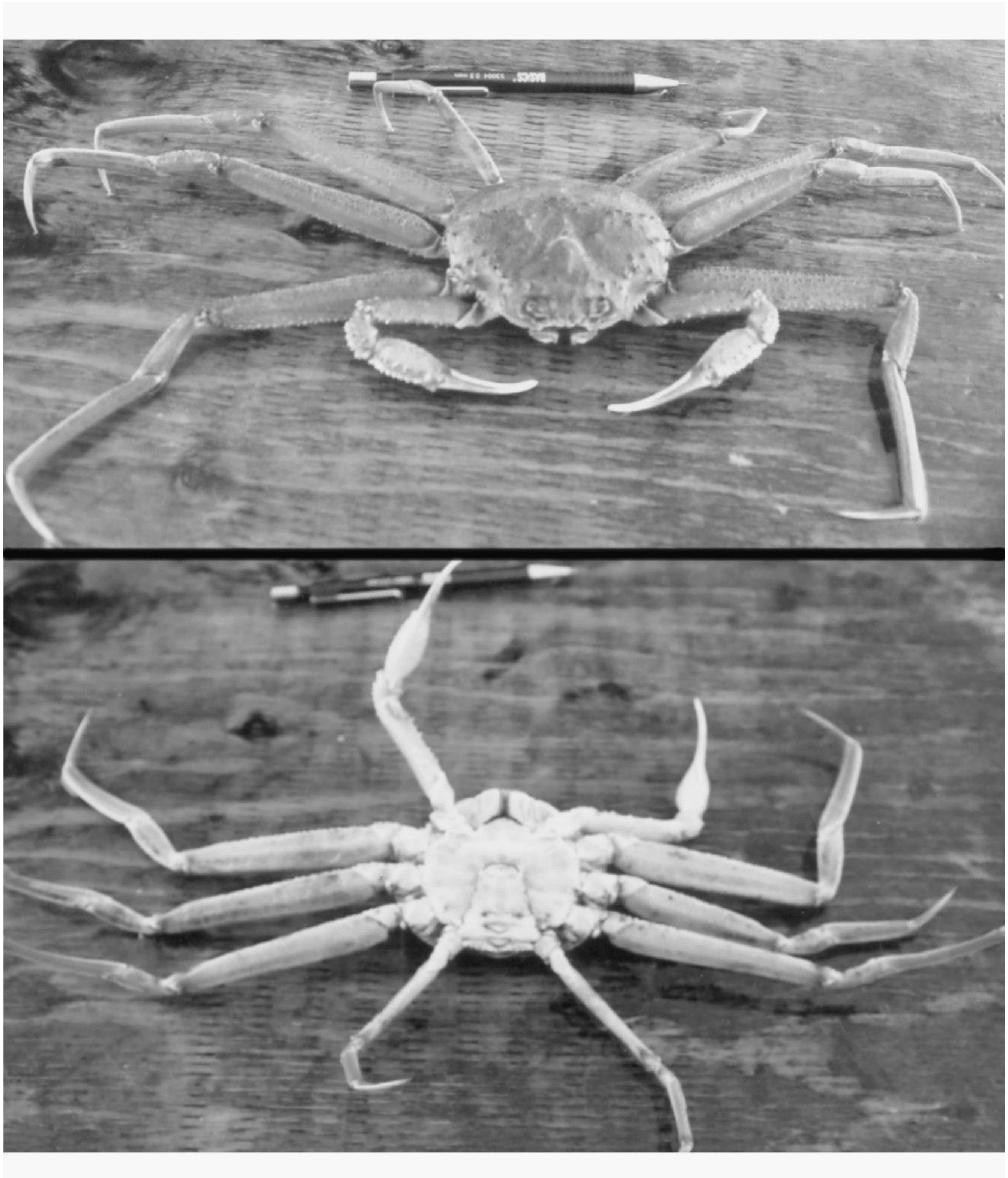


Figure 1: Dorsal (Top) and ventral (lower) views of a male Tanner crab (*C. bairdi*).

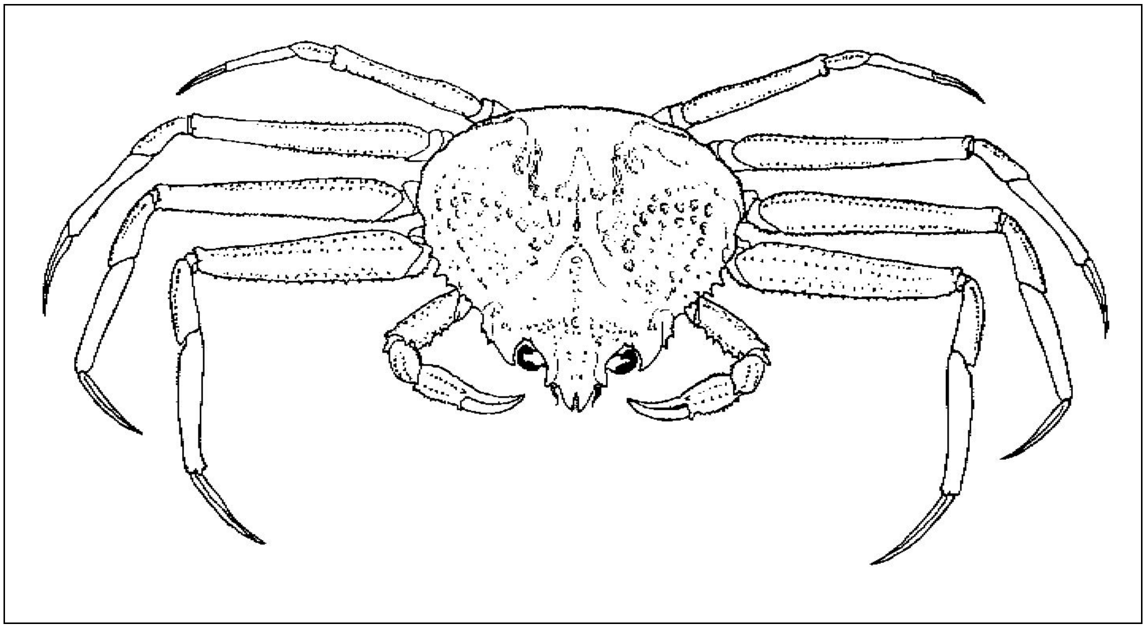


Figure 2: The Tanner crab, *Chionoecetes bairdi* (From Hart, 1982)

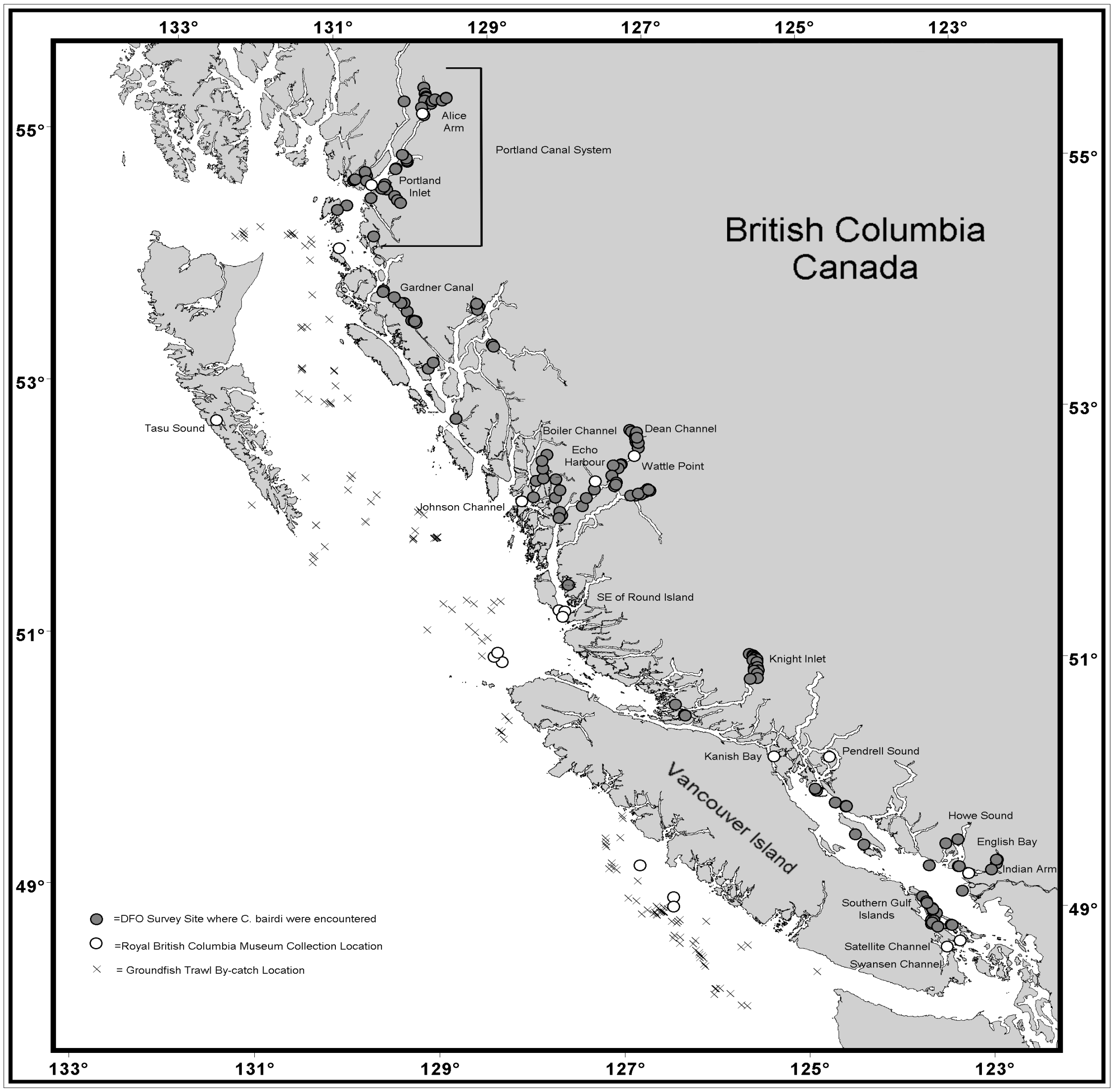


Figure 3: Locations of *C. bairdi* catch during DFO surveys (shaded circles) and Royal British Columbia Museum collections (open circles) as well as the location of reported *Chionoecetes* spp. by-catch, from < 350 m depth, in the groundfish trawl fishery

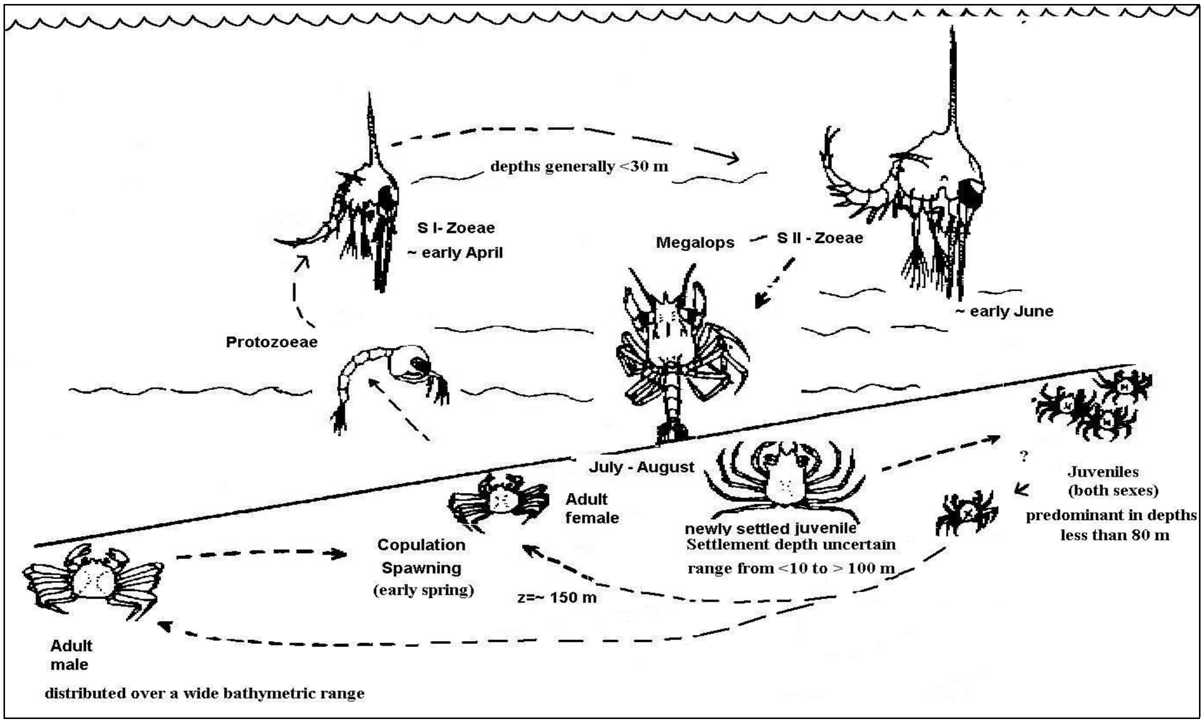


Figure 4: Migratory Pattern for *Chionoecetes bairdi* crab (Stevens et al. 1993)

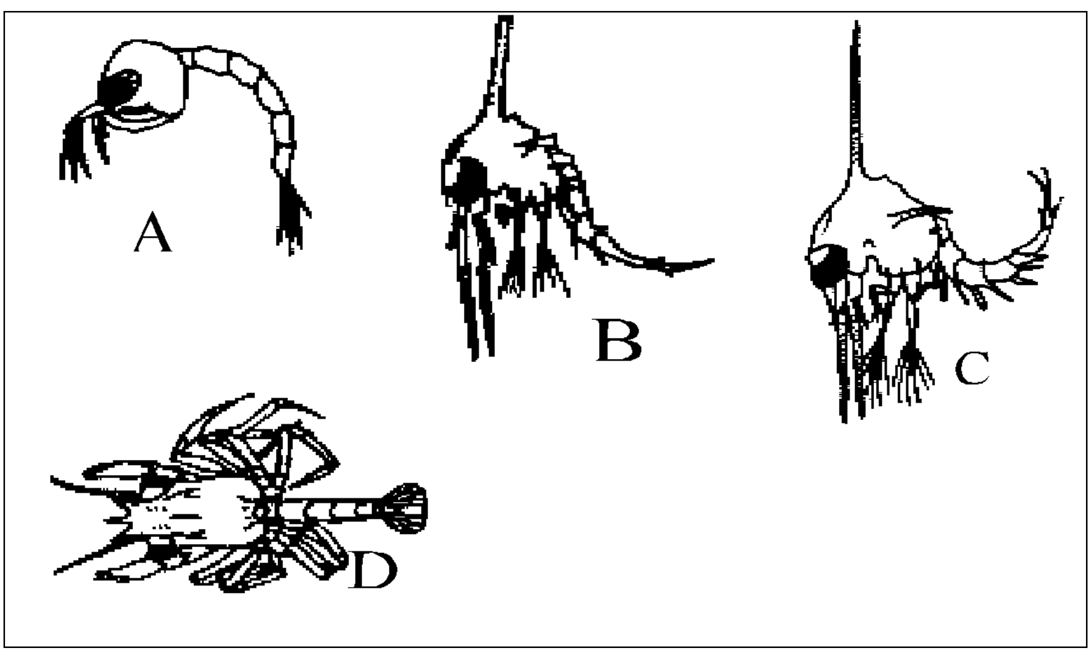


Figure 5: Schematic drawings of generalized tanner crab larval stages. A is the protozoea; B is the Stage zoea; C is the Stage II (SII) zoea; and D is the Megalops larva (Kon 1982)

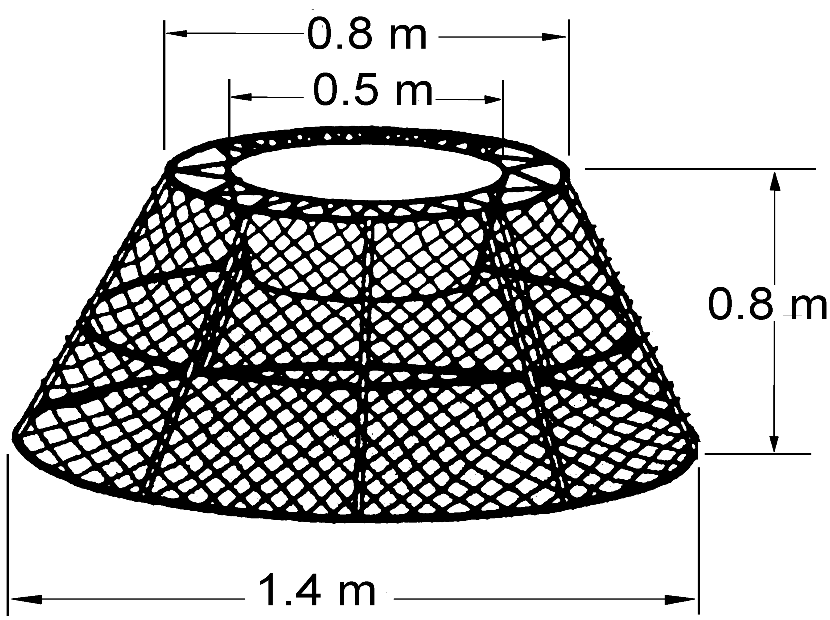


Figure 6: Typical Tanner crab trap

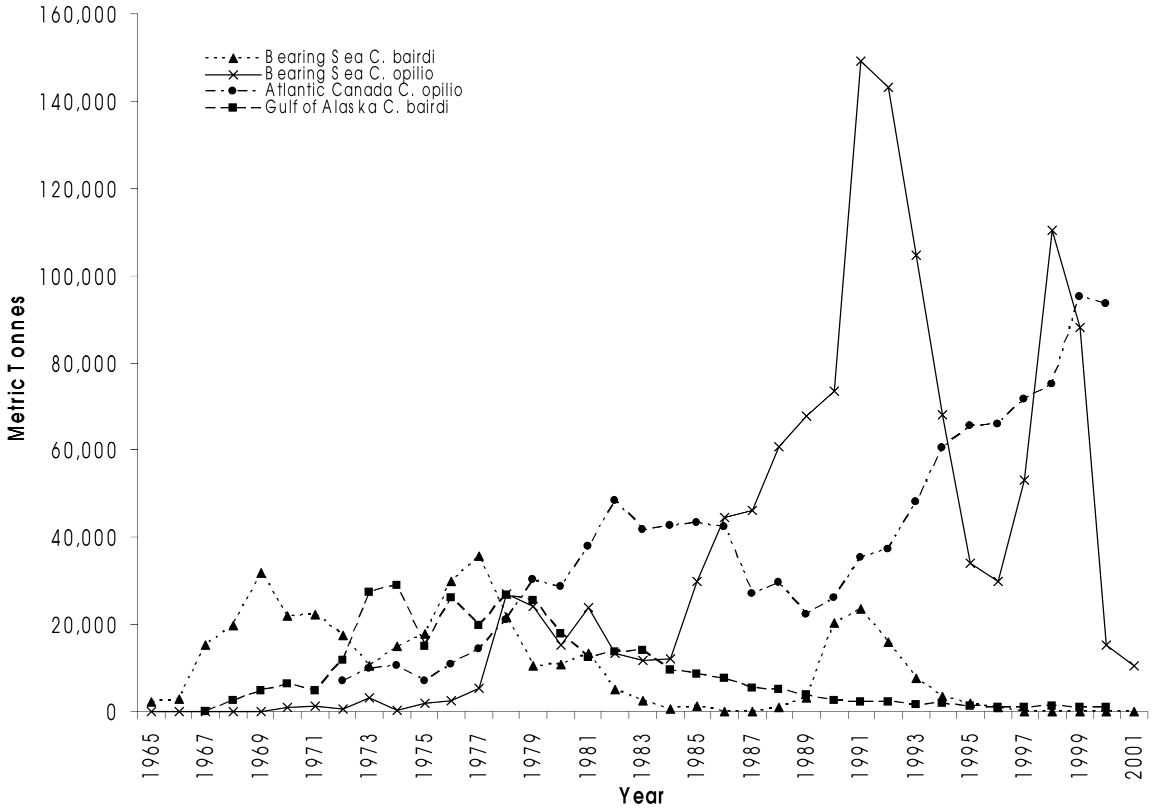


Figure 7: Catch History for the Alaska *C. bairdi* and *C. opilio* and Atlantic Canadian *C. opilio* fisheries (ADFG 2001, DFO 2001)

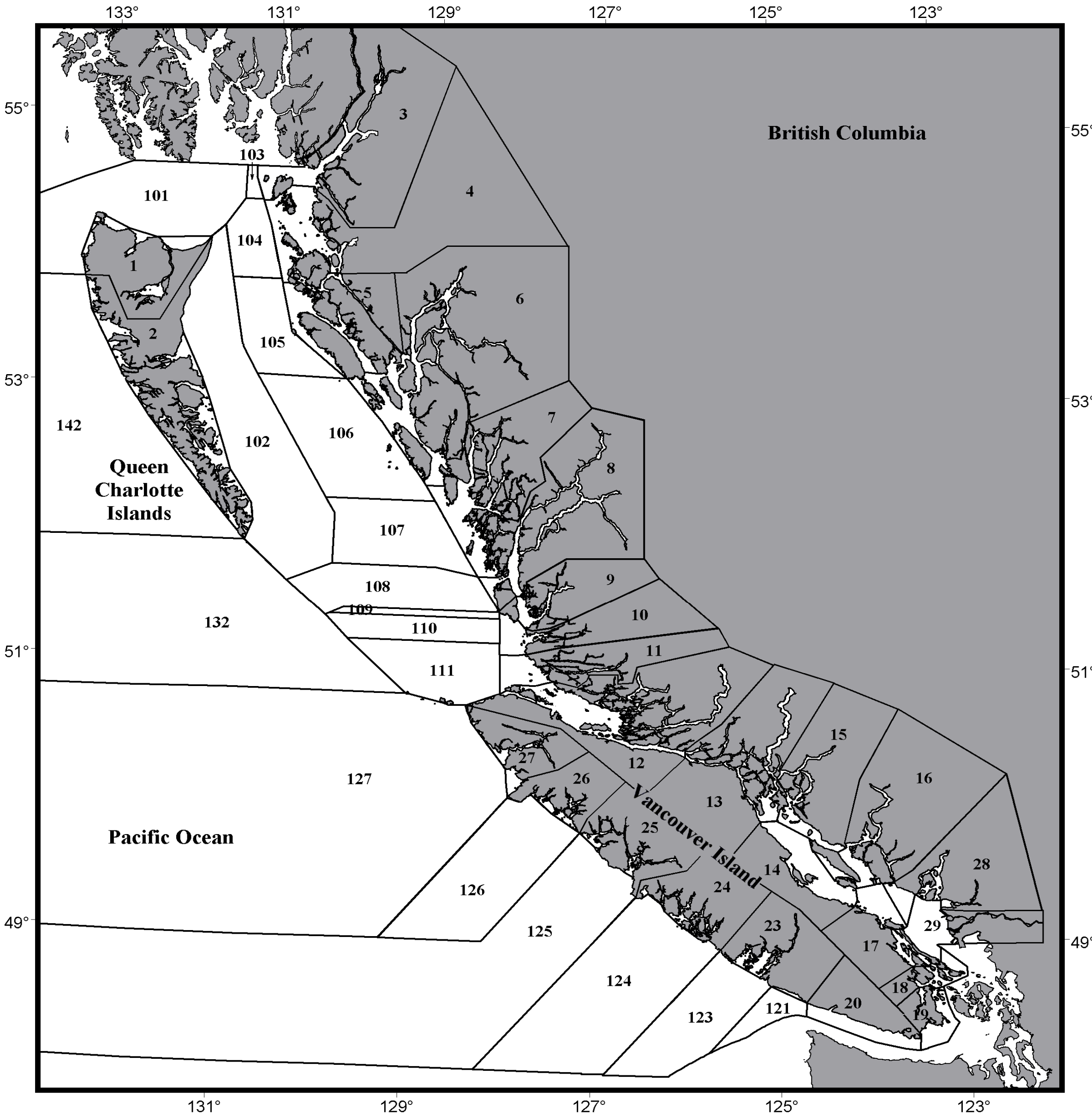


Figure 8: Pacific Fisheries Management Areas (PFMA) off the west Coast of Canada

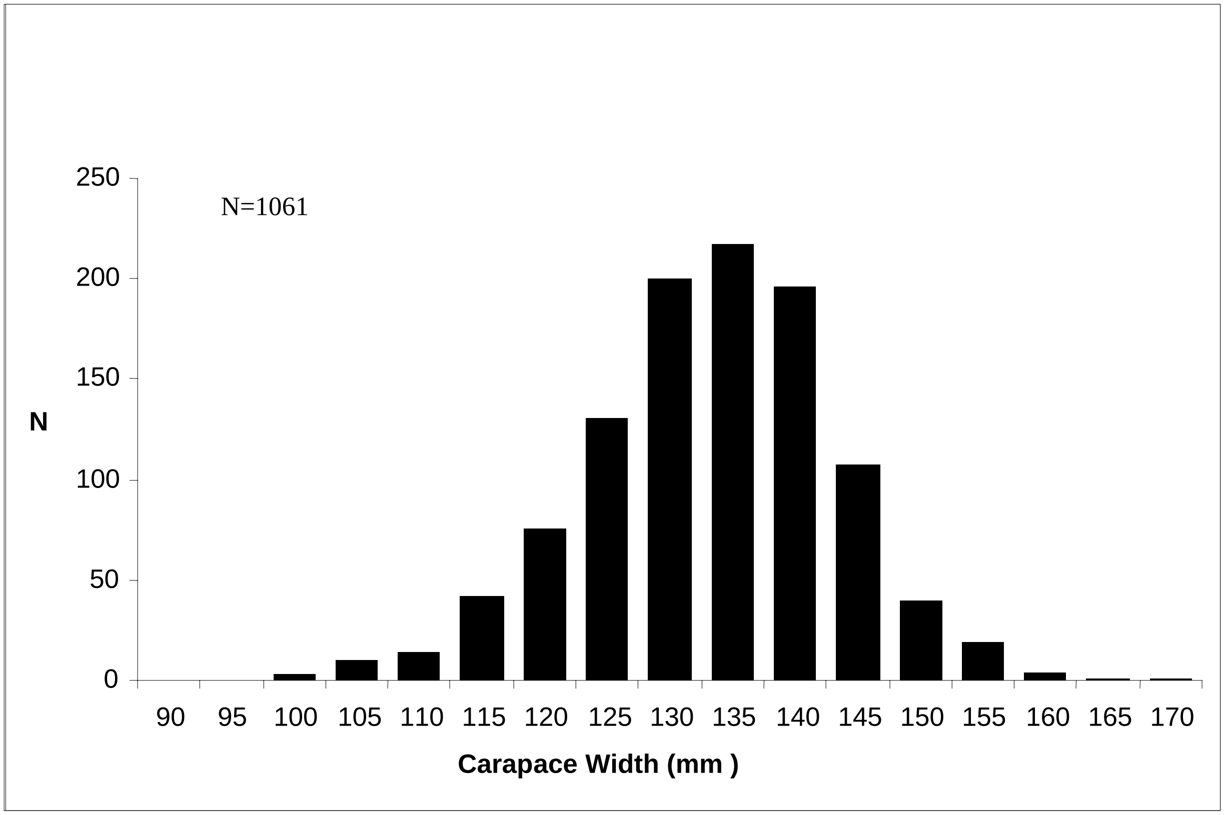


Figure 9: Carapace width histogram for Tanner crab caught during the North Coast King crab assessment survey May-June 1982.

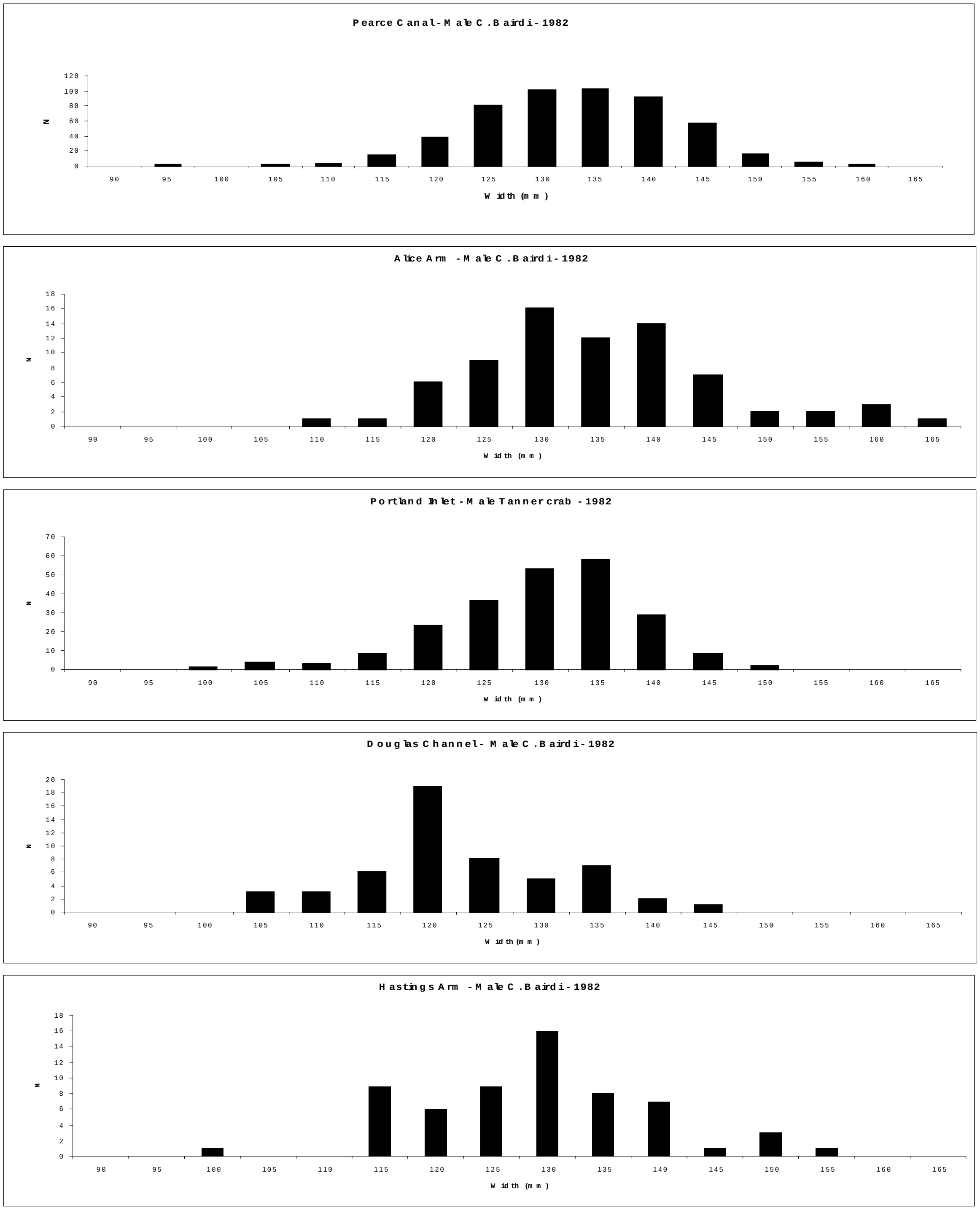


Figure 10: Width frequency histograms by inlet for *C. bairdi* caught during 1982 assessment survey. Top to bottom: Pearce Canal, Alice Arm, Portland Inlet, Douglas Channel, Hastings Arm.

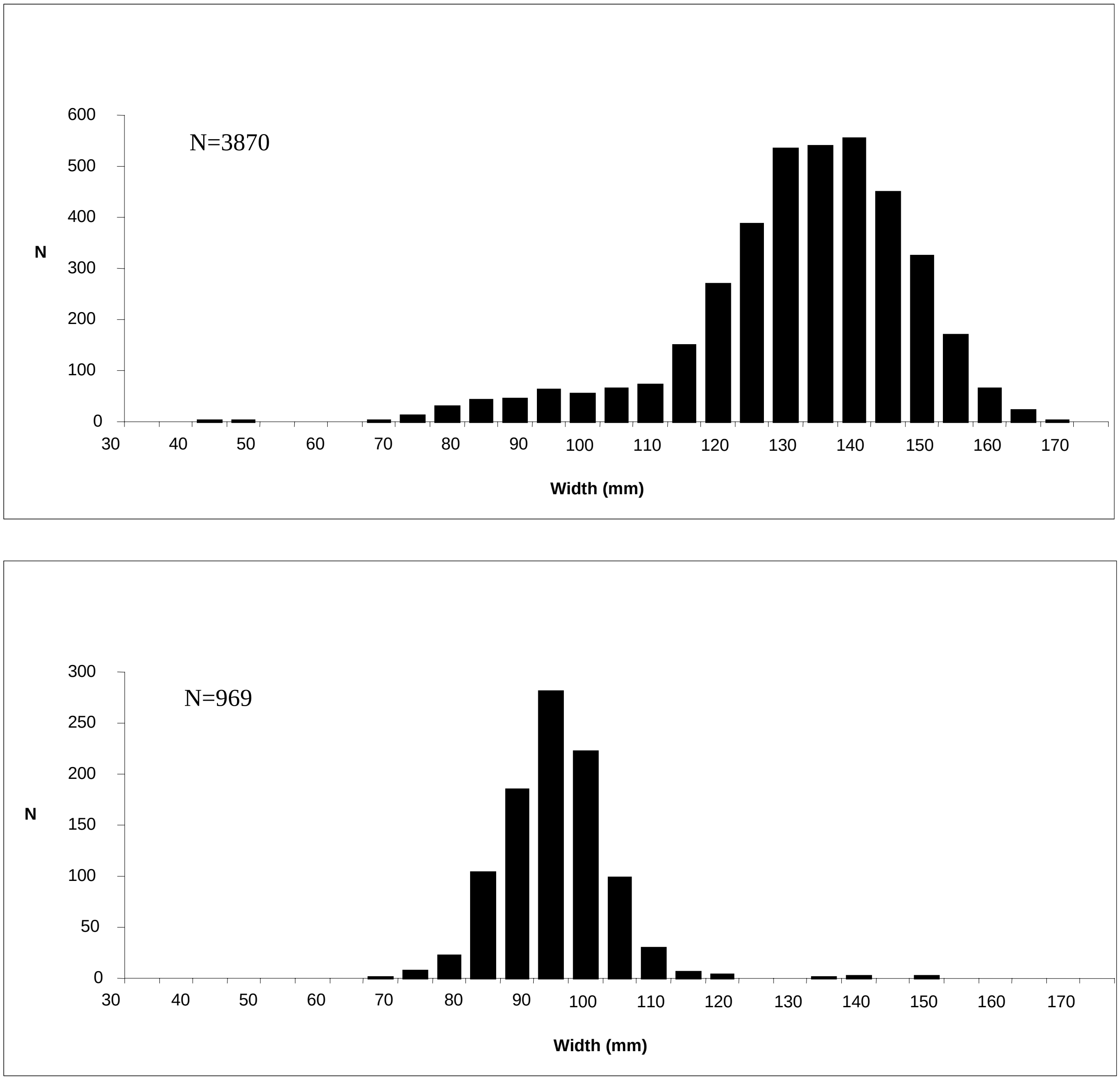
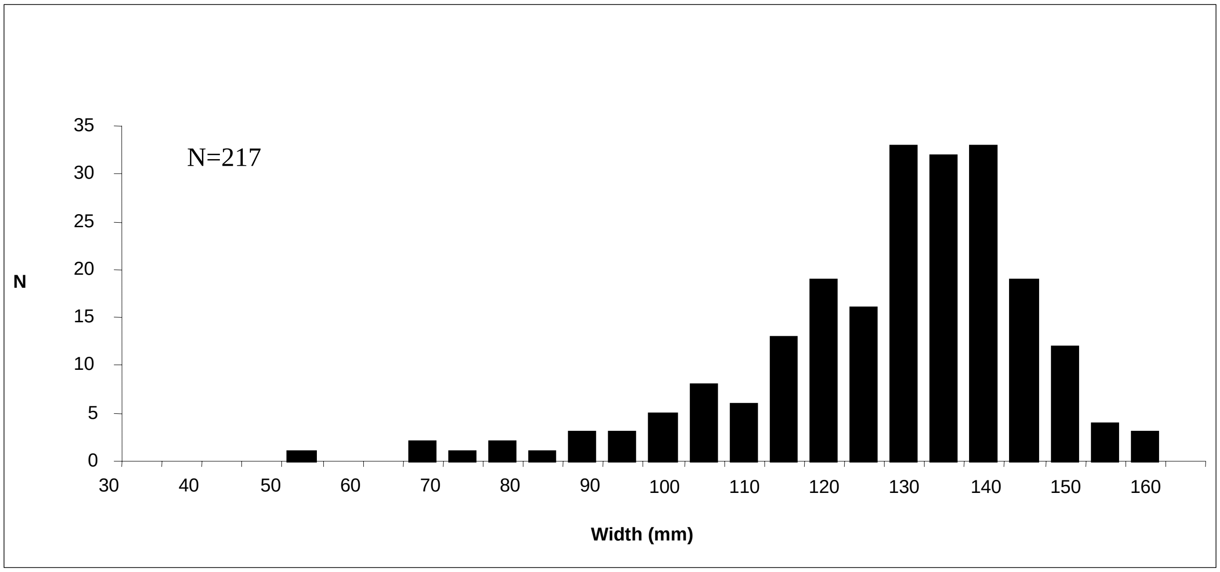


Figure 11: Pooled *C. bairdi* width frequency histograms from three surveys, Oct-Nov 1983, Feb-Mar 1984 and July 1983 (Sloan 1985). The top panel is males, the bottom females.



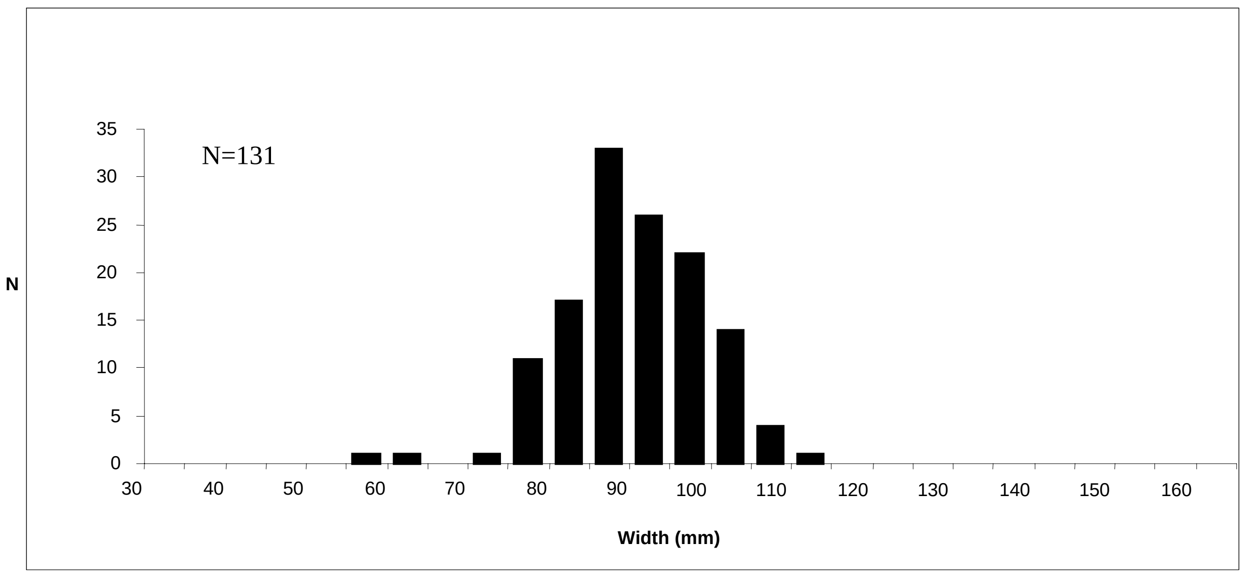


Figure 12: Width frequency histogram for male(top panel) and female (lower panel) *C. bairdi* caught in Knight Inlet during the Oct 1984 Tanner crab survey.

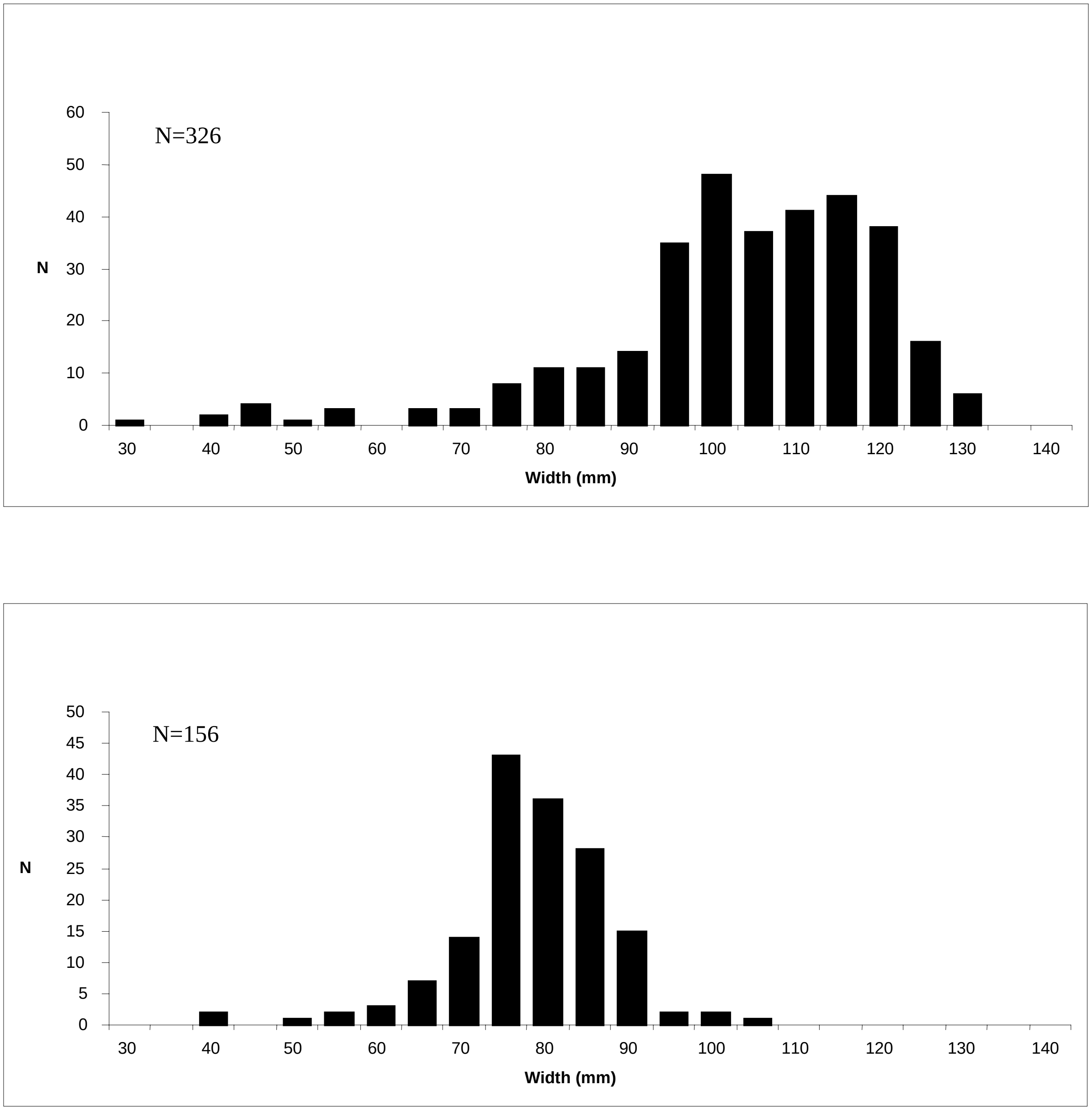
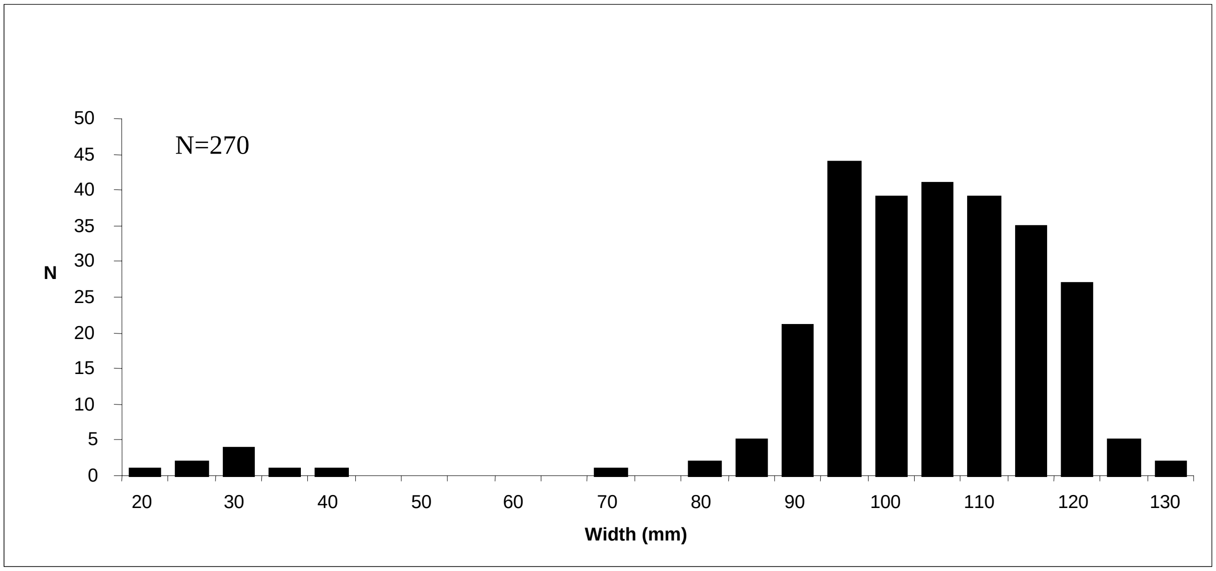


Figure 13: Width frequency histogram for male (top panel) and female (lower panel) *C. bairdi* from Dean Channel caught during the Oct 1984 Tanner crab survey.



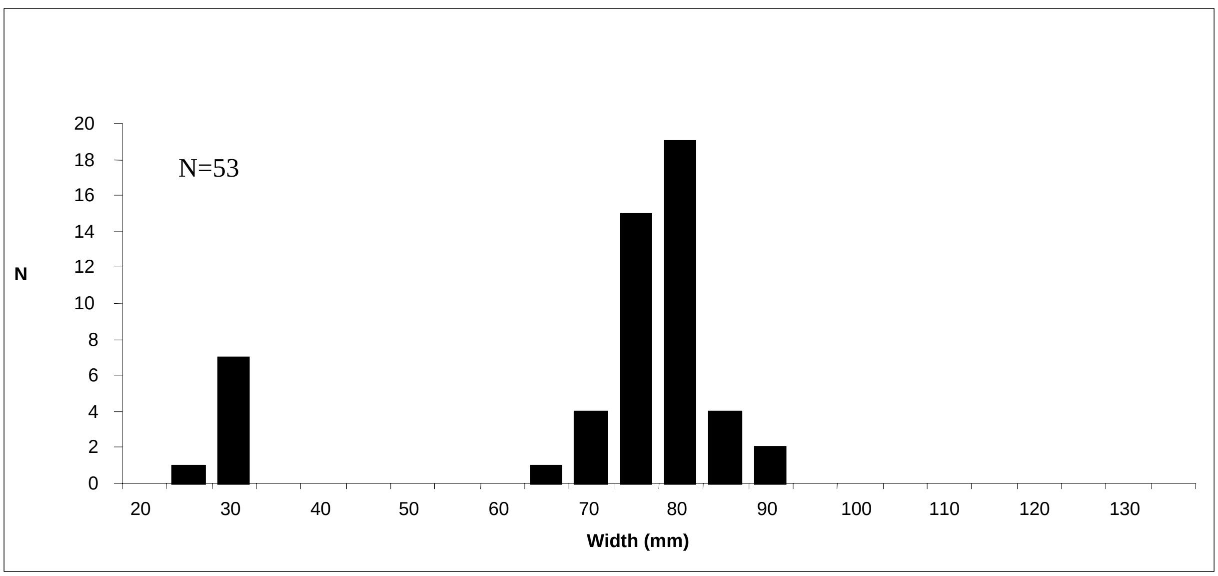
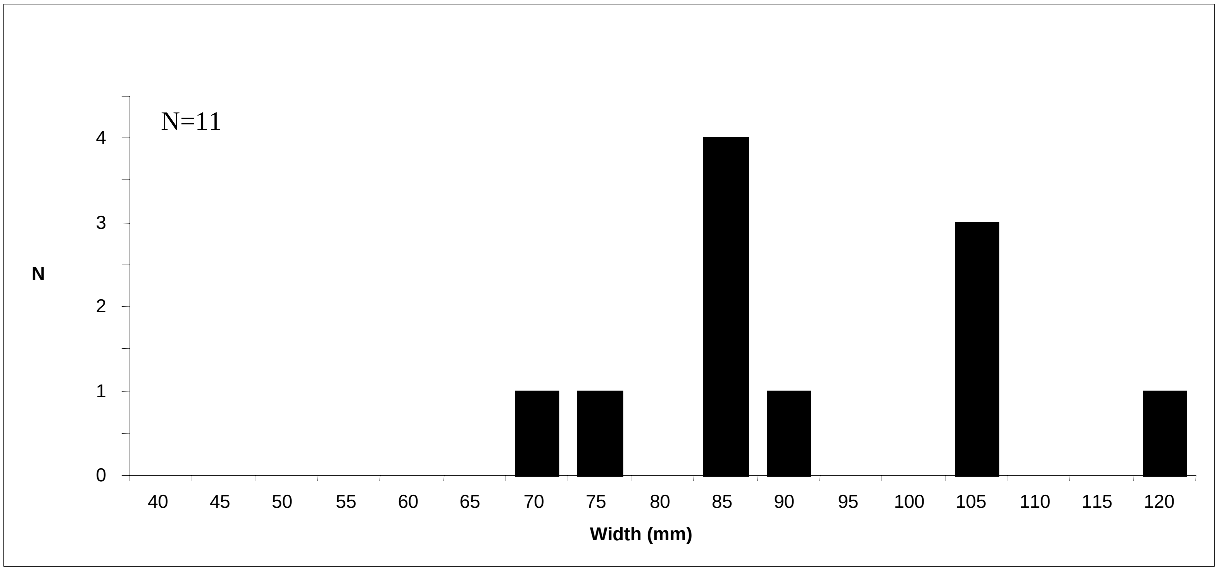


Figure 14: Southern Gulf Islands Tanner Crab Survey, March 11-14, 2000. Top Male, bottom Female.



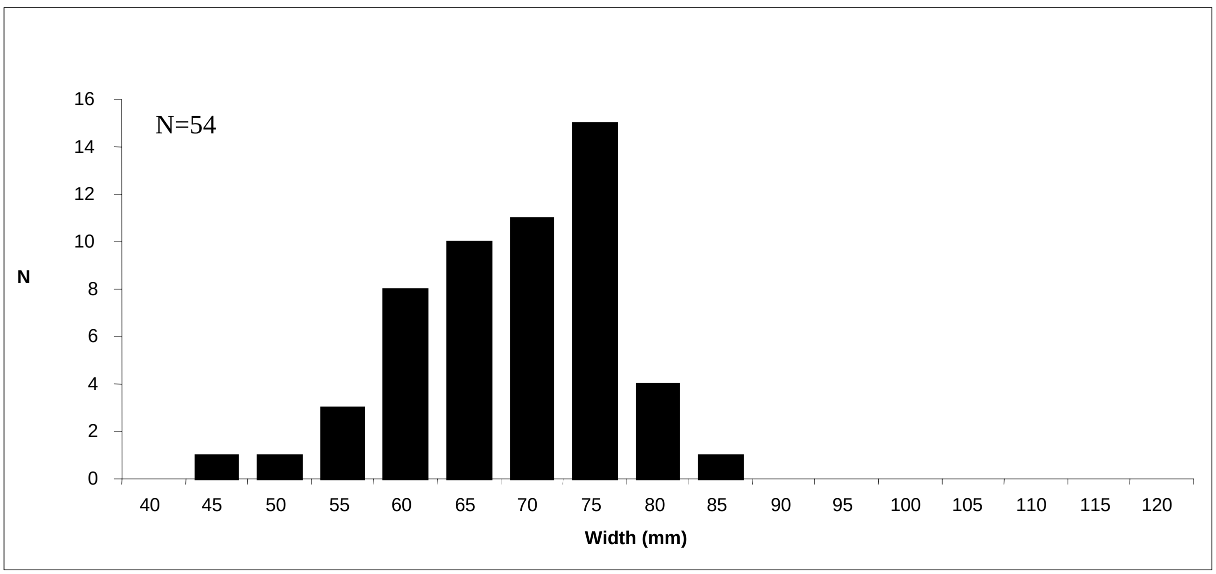
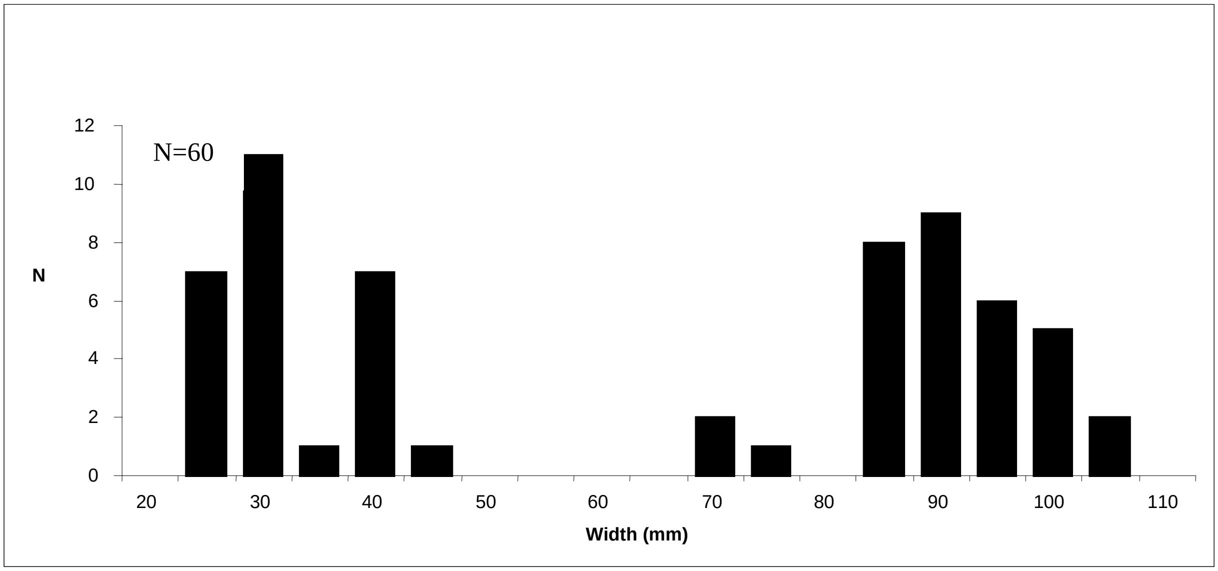


Figure 15: C. bairdi caught in Dean Channel during the 2000 CCGS Vector survey of the central coast of BC.



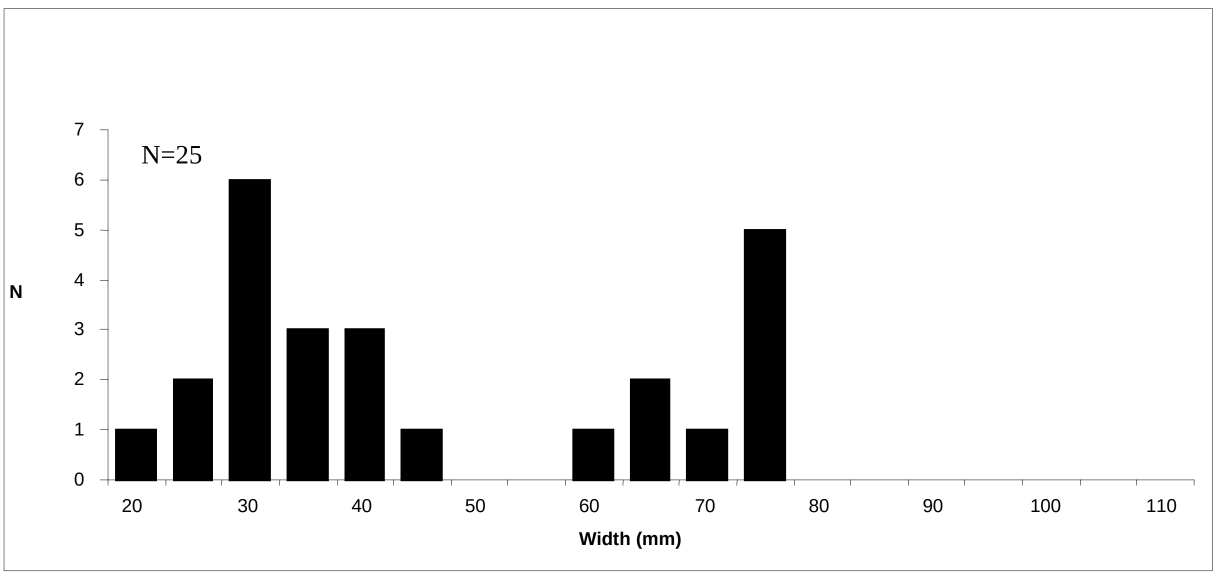


Figure 16: *C. bairdi* by-catch in prawn and dungeness crab traps in Howe Sound during annual DFO surveys.

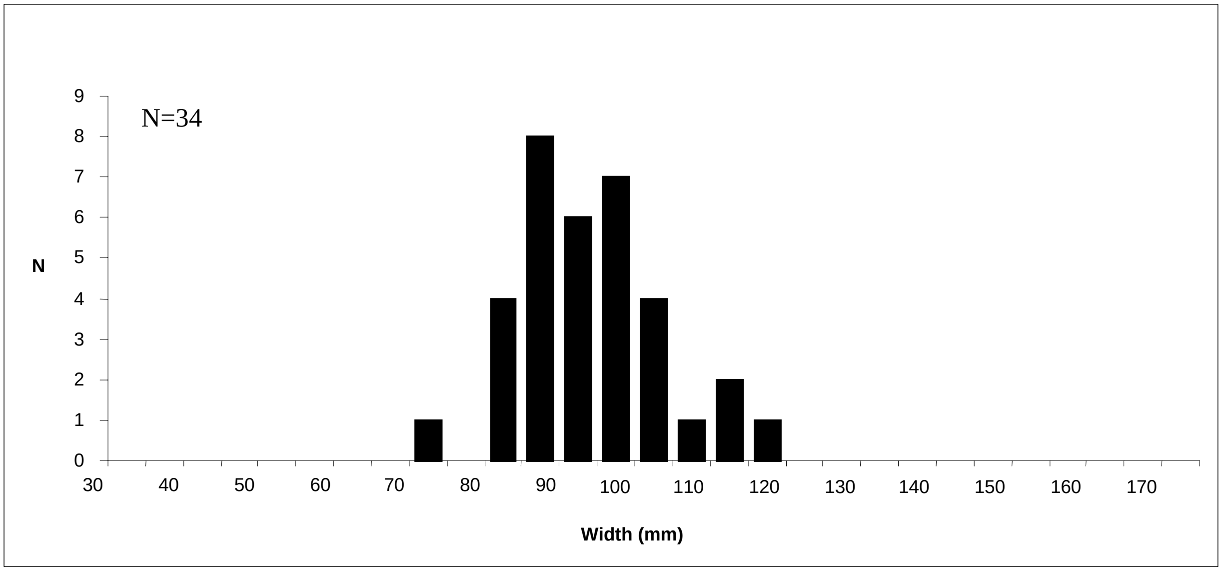


Figure 17: Width frequency of *C. bairdi* bycatch in the 2001 Georgia Strait Box crab survey.