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# Framework for a Tanner crab (*Chionoecetes tanneri* and *C. angulatus*) fishery in waters off the West Coast of Canada

J.A. Boutillier, R.B. Lauzier, A.C. Phillips and L. Barton

Fisheries and Oceans Canada
Pacific Biological Station, Stock Assessment Division,
Nanaimo, BC V9R 5K6

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## Abstract

A review and response to the results and recommendations on the initial Phase 0 review of Tanner crab (*Chionoecetes tanneri* and *C. angulatus*) is presented. A framework is presented for a Phase 1 management system including: stock definition; data considerations; assessment models and policy evaluations. Management options and data requirements including: size, sex and season; TAC's based on harvest rates or biomass estimates; target or reference point thresholds; area closures; and other management options are outlined. A survey plan for potential Tanner crab harvest areas is presented.

## Résumé

Une analyse des résultats et des recommandations du premier examen Phase 0 des crabes *Chionoecetes tanneri* et *C. angulatus*, ainsi qu'une réponse à ces résultats et recommandations sont présentées. Un cadre pour la Phase 1 d'un système de gestion est aussi présenté, incluant définition des stocks, considérations des données, modèles d'évaluation et évaluation des politiques. On présente aussi un aperçu des options de gestion et des besoins en données, incluant taille, sexe et saison; des TPA basés sur des taux de capture ou des estimations de biomasse; des seuils en termes de cibles ou de points de référence; des fermetures de zone, ainsi que d'autres options de gestion. Un plan de relevé des zones de pêche potentielles de ces espèces de crabe est aussi inclus.

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## 1. Objectives

This paper was produced at the request of the Invertebrate Subcommittee/Pacific Stock Assessment Review Committee (PSARC) and the Seafood Diversification Board as a follow up to the Phase 0 review of the Tanner crab (Phillips and Lauzier, 1997) presented to the Invertebrate Subcommittee of PSARC in July 1997. The main objectives of the paper are twofold: (1) to address the questions and concerns the PSARC Invertebrate Subcommittee had about Tanner crab fisheries in other parts of the world and (2) to provide a framework for the management of a new fishery which addresses the data needs for a sustainable fishery.

## 2. Introduction

As a result of a Phase 0 review of the biology and fisheries management on Tanner crabs, and their related species, the PSARC Steering Committee urged caution in the development of a fishery, as there appeared to be very few sustainable fisheries for these animals.

## 3. Phase 0: Results and Recommendations

The following recommendations were made by the PSARC Invertebrate Subcommittee following the Phase 0 review of the Tanner Crab fishery:

1. The Subcommittee noted that there were examples of failed fisheries but only one example of a sustained fishery on Tanner crabs. They recommended a review of the circumstances surrounding those failures;

2. Conventional management systems which solely depend on Size, Sex and Season (S/S/S) have limited usefulness at insuring sustainability, due to unique biological characteristics of the animals. It was recommended, therefore, that alternative assessment and management approaches be explored;

3. Assessment of Catch Per Unit Effort (CPUE) would benefit from the early imposition of standardized gear, and the Subcommittee recommended that this be undertaken from the outset of a fishery development;

4. The Subcommittee also stressed the need for accurate reporting of bycatch of invertebrates in other fisheries in the area, so that the total catch could be documented.

# 4. Response to Steering Committee and Subcommittee Concerns

In response to the Subcommittee suggestion for a review of circumstances surrounding the failures in other Tanner crab fisheries, we spoke with managers of these fisheries in Alaska (D. Jackson, ADFG) and on the east coast of Canada (M. Hébert, E. Dawe, D.M. Taylor, DFO)

## *4.1. Review of other Chionoecetes fisheries*

A review of *Chionoecetes* fisheries in other areas was provided in Phillips and Lauzier (1997) and Table 1, however a summary of fisheries performance and history of management strategies will be outlined to provide a background for management options.

The fishery for *C. opilio* in Newfoundland began in 1968, initially as a bycatch, but evolved into a directed trap fishery along the inshore areas of the northeast coast, and eventually to the offshore areas in the mid 1980s, when there was a collapse in the inshore areas. In the late 1980s quota control was initiated, and fishing seasons were redefined. Dockside monitoring was initiated in 1994, and expanded 1995. Individual quotas were expanded to include almost all fleet sectors and management areas by 1996. Management areas did not reflect stock structure, but were established as a mechanism to control the distribution of effort, and to prevent local exploitation. Landings have steadily increased from the late 1980s to the 1996 landings of 37,816 t, a record high. Effort has doubled from the late 1980s to 1996. Since the early 1980s, fishery independent trap surveys have been conducted in some areas, and fall bottom trawls were introduced in 1995 (Department of Fisheries and Oceans 1998a).

The fishery for *C. opilio* in Eastern Nova Scotia began in 1978, and collapsed in the mid-1980s. Landings from 1987 to 1993 increased steadily as a result of expanded fishing areas and effort. The 1997 landings were 1,691 t, a record high. Initially, this fishery was managed by size and sex restrictions. Between 1982 and 1993, management was based on effort controls (seasons, licenses and trap limits). By 1994, restrictions were placed on soft shell crab, and individual boat quotas, based on overall quotas, were introduced and maintained to 1997. In 1997, a fishery-independent abundance index was initiated using trawl surveys (Department of Fisheries and Oceans 1998b).

The fishery for *C. opilio* in the Gulf of St. Lawrence was initiated in 1965 with exploratory surveys, and evolved to a $150 million fishery by the mid 1980s, followed by a collapse in 1988-1989. The management of this fishery was complicated by regional socio-economic factors, such as competing inter-provincial interests, and minimum unemployment insurance requirements. Initial management measures were size and sex restrictions, followed by trap limitations and restrictions, soft shell restrictions, seasonal closures and limited entry in 1975. Trap limits were not perceived as a conservation measure, but rather as a method of distributing effort. A large increase in processing capacity in the mid 1970s, followed by an increased demand from Gulf snow crab in the early 1980s (due to the collapse of the Pacific fishery), resulted in record high landings of

31,585 t in 1982. In 1984, a 24,000 t quota for the mid-shore fishery was established with a 50-60% exploitation rate (Hare and Dunn 1993). By the late 1980s, it was evident that these measures did not adequately protect the reproductive capacity of the stocks, and these stocks were fully exploited and dependent on annual recruitment (CAFSAC 1989). By 1989, landings declined to 8,000 t (Hare and Dunn 1993). Since 1990, areas were closed when soft-shell incidence exceeded 20%. Quotas have declined from 1980 levels to reflect an exploitation rates of 30-40% of mature males in the combined areas of the southern Gulf of St. Lawrence, in comparison to previous exploitation rates of 50-60% (Hébert et al. 1997a). Landings in most areas had stabilized in 1997. Exploitable biomass is now determined from bottom trawl surveys (Department of Fisheries and Oceans 1998c).

In Alaska, *C. opilio* landings were first reported in 1970, increased substantially in the mid-1970s, stabilized in the mid-1980s, followed by huge increases exceeding 100 million pounds in the late 1980s. The record harvest was 328 million pounds in 1991. Landings decreased steadily from the record high to 65.7 million pounds in 1996. Initial management measures included size and sex restrictions. Since 1980, pre-season guideline harvest limits are set based on a 58% exploitation rate of mature males larger than 4 inches (102 mm), as determined from the National Marine Fisheries Service (NMFS) bottom trawl surveys. Other management measures include mandatory observer coverage, seasonal openings, area restrictions, trap limitation and trap design specifications to reduce bycatch and ghost fishing (lost or abandoned traps that continue fishing and retaining crab) (Witherall 1996).

Landings of *C. bairdi* in the Bering Sea have fluctuated widely: 70 million lbs. in 1969, declining to 23 million lbs. in 1973, increasing to 78 million lbs. in 1977, collapsing to 5 million pounds to 1983, and no harvest in 1986 and 1987. This fishery recovered to almost 52 million pounds in 1991, and again collapsed to 1.8 million lbs. in 1996 (Phillips and Lauzier 1997). Since 1980, pre-season guideline harvest limits are set based on a 40% exploitation rate of mature males larger than 5.3 inches (135 mm), as determined from the NMFS bottom trawl surveys. Other management measures include mandatory observer coverage, seasonal openings, area restrictions, trap limitation and trap design specifications to reduce bycatch and ghost fishing. In 1995, NMFS bottom trawl surveys indicated the eastern Bering Sea stocks were at very low levels, and very poor recruitment was forecast in the coming years. The Aleutian Islands stocks are very small, and limited to a few large bays and inlets. Trawl surveys indicated a dramatic decline in stocks from 1991 to 1994. There were no landings in 1995, and in 1996 there were very limited landings in the Western Aleutians. (Witherall 1996).

In Alaska, fisheries for *C. tanneri* and *C. angulatus* have only occurred in the past few years, and there is only very limited interest in these species, due to the limited habitat in the Gulf of Alaska, the logistics of fishing at depth, as well as the price paid for these species, in comparison to *C. opilio* (D. Jackson, pers. comm.). These species are managed by gear restrictions, effort, harvest level and season openings. The 1997 harvest limits in each management area were based largely on historic harvest levels and trends in

CPUE. In some areas, the guideline harvest level was set at 100,000 lb. to accommodate exploratory fisheries. Each management area is managed as a separate stock.

There has been very little Tanner crab harvest in Oregon. Present regulations for *C. tanneri* include harvesting with Dungeness crab gear. There are no size restrictions. Most of the Tanner crab is caught as by-catch in the trawl fishery (McCrae 1994).

Many of these fisheries have undergone radical changes in management away from size, sex and seasonal restrictions after the initial collapse of the stocks. All the fisheries now have one thing in common, the management system includes a catch ceiling, many of which are set using fishery independent assessment trawl surveys (except Oregon). There are a number of hypotheses about why the size, sex and seasonal management system failed. That could include factors such as:

1. Reduction in breeding success of the multiparous females, which make up the largest component of the breeding stock, i.e. these crabs seem to have complicated breeding behavior in which newly molted mature male crabs can only successfully mate with primiparous females, as the multiparous females tend to reject them. It is speculated that if this occurs, this large multiparous female component of the stock would become unproductive, and would also inhibit recruitment of new females (Phillips and Lauzier 1997).

2. Unaccounted incidental mortality on the non-target component of the stock. In Alaska, they assume 100% handling mortality of captured deep water Tanner crabs (D. Jackson, pers. comm.). On the east coast, they believe that the incidental mortality on the shallow water species is quite low, although it is known that susceptibility to mortality of this species is due to a number of factors: the vitality of the crab after handling; the number of missing legs; the body size; and the degree of desiccation of the crab (air temperature, duration of exposure and average wind speed) (Dufour et al. 1997).

3. Populations of animals which undergo large natural fluctuations in recruitment, require more active management than passive size, sex, and season. As was pointed out, in the Phase 0, by Phillips and Lauzier (1997), these crab stocks tend to show large fluctuations in recruitment. Sustainability is based on management of balancing strong and weak year classes to ensure an annual viable fishery. There are both biotic and abiotic factors which appears to explain some of the large recruitment fluctuations. The one hypothesis put forward for *C. opilio* explaining the recruitment fluctuations, was that the carrying capacity for juvenile rearing areas is reached when large year classes successfully recruit to the area (Sainte-Marie et al. 1996). As the total juvenile area is occupied, new year classes fail due to competition and predation by older year classes. A year class will occupy the juvenile areas for up to 5 years (Department of Fisheries and Oceans 1997). Once the larger juveniles leave the rearing areas, there is then room for successful settlement of new year classes as long as there are sufficient larvae to settle out. Another explanation for fluctuations is the influence of temperature, with lower temperatures producing better recruitment

(Lovrich et al. 1995). This in part seems to be tied to low temperature reducing the number of predators, such as cod. The distinction between these two critical driving factors is extremely important, as the endogenous response may be manipulated by the fishery, while the environmental component can not be manipulated, but must still be planned for to insure there are sufficient stocks in place to weather unfavourable environmental conditions.

# 5. Phase 1 Framework

The Phase 1 management system as described by Perry et al. (1998), is designed to allow a fishery to proceed cautiously and in a manner which allows for key information needs to be collected. This cautious approach allows for a sustainable fishery to develop in a manner which in no way compromises the conservation of the target species or co-occurring bycatch species. In learning from the other fisheries on Tanner crabs and related species, it is advisable that the management system that is adopted for fisheries off the west coast of Canada, must not solely rely on passive size/sex/season management efforts to ensure conservation. The management system must actively monitor stock condition, set appropriate fishing exploitation levels and be able to respond in a timely manner.

The U.S. National Research Council publication on Improving Fish Stock Assessments (1998), gives a checklist of four basic groupings of items that should be included in a stock assessment: Stock Definition, Data, Assessment Model and Policy Evaluation. Under each heading are a number of criteria and important considerations. Our approach is to address the important consideration under each heading such that we can identify and discuss potential key data requirements. We also address additional considerations in developing new fisheries.

## *5.1. Stock definition*

At the present time we can only define the spatial scale of the stocks under consideration by defining their potential habitat, i.e. the offshore areas of British Columbia waters between 400-900 m depth (Figure 1). To get a more accurate picture of the stock distribution, we need to have a fishery that will be conducted in a manner that will test the boundaries of the species distribution and a subsequent sampling program which will address stock definitions. A program designed to understand the distribution of animals was conducted off Nova Scotia in an experimental area (Hébert et al. 1997b). The area was divided up systematically in equal sized blocks where fishers were required to fish at least one day in each of multiple blocks in the experimental areas. After fishers met this condition of licence, they were allowed to fish anywhere in the area to reach their precautionary limit.

This assessment must be spatially structured, there are many examples of quite separate areas occupied by the different ages and sexes of animals in the scientific literature (Phillips and Lauzier 1997).

This will also be a multi-species assessment for both *C. tanneri* and *C. angulatus* (the target species), due to their overlapping distribution, and possibly for *Lithodes aequispina* and *L. cousii* as co-occurring species (Jamieson et al. 1990).

Tools which are available to define stock structure include: tagging; micro-constituents; genetics; and morphometrics. Consideration needs to be given on the most appropriate application of the available tools for stock definition.

## *5.2. Data*

There are a number of data concerns, issues and constraints which need to be considered when designing an assessment framework. These issues are addressed below, with suggestions for their resolution.

### 5.2.1. Removal estimates

All removals must be included in the assessment. The fishery has to be conducted in a manner which allows for measurement of the catch in terms of numbers and size landed, as well as discards and their subsequent mortalities. This would require a logbook which documents all of this data, as well as a series of tagging experiments which evaluates the handling mortality of discards. It would also include fishery induced mortality estimates from ghost fishing pots. As pointed out previously there seems to be quite different opinions as to the seriousness of handling mortality of discarded crabs. Extensive work has been conducted on eliminating the catch of discards through gear modifications, and or time/area closures, especially for soft-shelled animals. Stevens (1997) defined the ideal crab pot for Tanner crabs as a conical or pyramidal trap with a circular top opening, a bait container near the center of the pot, a plastic collar to prevent escapement of legal sized crabs, an excluder ring around the top of the pot to prevent entrance of under-sized crabs, escape rings near the bottom, and large areas of degradable mesh.

### 5.2.2. Abundance estimates

We need to determine if the estimate of abundance is absolute or relative, and what proportion of the stock is estimated. Biomass is usually estimated through some enumeration process which calculates biomass as the product of density per unit habitat area times the area occupied. As was pointed out in the fisheries for these species in other parts of the world (Phillips and Lauzier 1997), this is done through fishery independent area swept trawl surveys. In general, these biomass estimates are only relative indices of abundance. These estimates are then combined with information on removals (catch), growth, recruitment and natural mortality and modeled. These models can vary from simple biomass dynamic models based on surplus production, or delay-difference relationships, or complex age-structured synthesis or virtual population analysis (VPA) models, to give estimates of absolute abundance. Catch per unit effort (CPUE), as an index of abundance, is fraught with problems including hyperstability, unstandardized fishing effort, change in catchability etc. (Hilborn and Walters, 1992).

There are a number of suggestions for ways of getting around this, by Perry et al. (1998), such as tagging and depletion experiments. Each of these techniques, however, has its own suite of problems. Tagged animals returned to 400-900 m, may experience very high mortality. If this were the case, then lack of tags returns could either be explained as low exploitation rates, high discard mortality, or high rates of dispersion. Through the use of observer data, mass marking of discards and an evaluation of the effectiveness of an escape port or excluder entrance, we will get a better appreciation on the scope of the problem.

#### 5.2.3. Gear saturation and CPUE

Gear saturation can be a major problem when measuring CPUE. There are a number of factors which affect effort, such as size of trap, soak-time etc. These criteria need to be understood when standardizing effective effort so that an appropriate CPUE index can be calculated. Without standardization and with gear saturation occurring, the CPUE index will remain stable, in spite of extensive removals, and it will be impossible to get reliable estimates of the initial index of $B_0$.

#### 5.2.4. Age, size and sex

Information on age, size and sex-structure is required, considering the complex growth patterns of the animal, the unusual mating behavior and the spatial segregation of the various age and sex classes. This information is critical, if we are to understand the impact of the fishery on the population. However, one must be very careful in the design of the collection process, if we are to get a truly representative sample of the population structure. Information solely from the commercial fishery will be insufficient to give us a complete picture of what is happening to the population. Therefore, it will be impossible to monitor the stock and evaluate the effectiveness of management actions, without a fishery independent component.

#### 5.2.5. Tagging experiments

There are a number of inherent problems with tagging experiments and resulting data. Some of the problems have been mentioned above, with respect to unknown mortality rates from handling and returning animals from this depth range. In addition, the tagging process must be designed in a manner which insures that tags endure molting, to assess non-terminal molt animals.

#### 5.2.6. Environmental data

The environment at this depth is relatively stable (Gage 1991), most of the environmental impacts will probably be associated with affects of currents on larval dispersal. To understand the critical factors that control recruitment, we must first understand the distribution and migrations of the animals more thoroughly. Understanding the environmental factors controlling larval distribution, and movement are critical to determine the spatial scale for management purposes, as well as predicting variability in recruitment. Environmental factors may be indirect, in that they may have an effect on potential predators, rather than a direct affect on the crabs themselves.

## 5.3. *Assessment models*

We need to estimate important parameters like natural mortality (M), vulnerability, fishing mortality (F), and catchability, and determine if they are constant. Preliminary estimates of appropriate exploitation levels are usually based on some proportion of estimates of natural mortality. Patterson (1992) suggests that $F_{opt}$ may be most likely in the order of 2/3M when a population is at optimal production levels. Using Hoenig's (1983) equation for calculating M given maximum age:

$$\ln(M) = 1.44 - 0.982 \ln(t \max)$$

we get a range of 0.28 to 0.55 (Table 2) for estimates of instantaneous mortality (M), depending on maximum age chosen (for these animals) varying from 8-16 years.

## 5.4. *Policy evaluation*

### 5.4.1. Alternative hypotheses

A number of alternative hypotheses have been considered, but their respective weighting has not been determined. One critical hypothesis is around the definition of stock, and the spatial scale by which we manage the fishery. We need to determine whether there is one large stock off the west coast or whether there are a number of smaller isolated populations. For this area, there do not appear to be any physical barriers that would indicate isolated populations. However, there may be oceanographic conditions or biological considerations which could lead to population isolation. With the definition of stock in question, there is a greater risk of overfishing associated with managing the system as a single large stock, if in fact, there were a number of small isolated stocks, as opposed to managing the system as a number of small stocks, when in fact there may be only one large stock. Another hypothesis which would have severe effects, is the assumption around terminal molt. Paul and Paul (1990) found small mature male *C. bairdi* molting, in contrast to *C. opilio*, which exhibits a terminal molt. If animals do not have a terminal molt, then the calculation of a size limit set to optimize yield per recruit would be based on an entirely different set of parameters. Also, those species that have a terminal molt, such as *C. opilio* on the East coast, are typically fished down heavily early in their terminal molt, to avoid old shell crabs, which have reduced marketability.

### 5.4.2. Alternative harvest strategies

A number of alternative harvest strategies have been considered:

1. Passive size/sex/season management has shown to be ineffective at insuring sustainable fisheries for animals with such highly variable recruitment. However

these passive management actions are extremely important when dealing with issues such as growth overfishing, reduction of bycatch, and optimization of product quality through soft-shelled closures. Most of the fisheries around the world on these and related species have now adopted a management strategy which employs output controls of catch through TACs or fixed exploitation rates.

2. A selective fishery for males only may have severe consequences, if the exploitation level on this component of the stock inhibits successful fertilization and subsequent recruitment. Setting quotas and exploitation levels would have to be based on a component of the stock being exploited i.e. if the fishery is male only due to size limit (market restrictions), then the quota is based on only that component of the stock. There is a possibility of a roe market, which may influence harvest strategies (P. Edwards, pers. comm.).

3. We need to determine an appropriate size of exploitation and whether this matches with size at maturity. We also need to determine whether the size limit for conservation purposes is to prevent recruitment overfishing or to prevent growth overfishing. In both cases, we have to determine molting patterns, the age of the animals, their natural mortality rate, and whether there is a terminal molt once they reach sexual maturity.

### *5.5. Fishery development*

We need to determine the real "objective" of the fishery and what are the best indicators of performance. Walters (1998) goes through an estimation procedure for losses in newly developing fisheries. Assessment of risk of loss assumes that there is baseline information available at the start of development. Included in his data requirements were estimates of natural mortality (M) and Ford-Brody growth parameter of intercept and slope of body weight. These are used to then calculate $F_{opt}$. He also assumes enough exploratory fishing and survey information to provide minimum and maximum estimates of unfished biomass, $B_0$.

Walters (1998) points out the two very different viewpoints about investment in information gathering during fishery development. One suggests starting with catch-effort data and analyses, and then moving toward detailed age-structured modeling. The other suggests emphasis on analysis of productivity bounds for biomass and sound indices of relative abundance, that can be used later in depletion analysis. The first case is justified by the idea that the fishery needs to prove its economic potential before you invest in substantial research and assessment. The second is based on the history of fishery development, which shows that fisheries do not develop in this slow safe way, and that the data in the beginning is very suspect. In fact both these techniques are presently used in the sea cucumber (*Parastichopus californicus*) fishery in British Columbia (Boutillier et al. 1996a) where 25% of the coast is reserved to collecting information in the traditional manner using CPUE geo-referenced data and associated analyses, another 25% of the coast is presently being exploited under a regime which provides fishery independent biomass estimates and variable exploitation rates, which will test the productivity of the stocks at various levels .

# 6. Management options and data requirements

Perry et al. (1998) show a decision tree illustrating two major regulatory strategies for fisheries: (1) total allowable catches; (2) or effort controls. With each of these strategies, tactics and the risks associated with each tactic, are identified. Only two tactical choices did not have the risk of overfishing readily associated with them, and they were under total allowable catch (TAC) using biomass estimates from surveys, and effort regulations imposing large area/time closures. In both these cases, the major risk was associated with missed fishing opportunities.

## 6.1. *Previous C. tanneri exploratory fishery in B.C.*

In the initial British Columbia fishery for *C. tanneri* in 1988 and 1989, landings were modest (1988: 0.5 t; 1989 35.5 t) (Jamieson 1990). The unstandardized catch rates varied from 7 to 13 crabs per traps, and appeared to be relatively consistent throughout this depth range, although occasionally one trap might contain up to 40 individuals, while others contained one or none. Gear was variable, and included 53 inch base conical traps, 53 inch tapered traps, stacking square traps, 8 ft. x 7 1/2 ft. conical traps, and 6 ft. x 6 ft. x 4 ft. square king crab type pots. Most gear was set in strings of 40-100 traps, and soak times varied from 1 to 10 days, with occasional long soaks due to gear loss and subsequent recovery. The depth ranges exploited by the industry varied from 500 to 700 m and was concentrated in Areas 124 and 125.

Biological samples from sampling conducted on the W.E. Ricker, and a few commercial samples during the initial fishery in 1988, gave us some limited information. A width frequency analysis of crabs sampled by trap from the W.E. Ricker during May 1988, shows that 98.6% of the crabs caught were above the minimum size limit of 100 mm carapace width, employed during the initial experimental fishery. If 127 mm is used (Alaskan regulations), then 86.7% are still above the legal minimum size. The sample mean was 144 mm, with the mode from 130-155 mm. Maximum size was 188 mm (Figure 2), which is greater than the maximums reported from Oregon (180 mm - Pereyra (1967), and 162 mm -Tester and Carey (1986)) or from Alaska (170 mm. - Somerton and Donaldson (1996).

Width at 50% maturity for *C. tanneri* was calculated to be about 118 mm (Tester and Carey 1986, Somerton and Donaldson 1996), but the size at which they become functionally mature is uncertain. It is not known if there is a terminal molt in this species, and there is insufficient data to relate carapace width to claw differentiation, which is probably a better indicator of maturity. It would appear from all sources, that the bulk of the adult male population is above the regulation width of 127 mm.

### 6.2. *Phase 1 objectives*

The objective of a Phase 1 management strategy for new and developing fisheries is to ensure conservation goals are met, while creating a system which will provide the information requirements necessary for a sustainable fishery. A key element that should be included in a Phase 1 strategy is to provide for testing of critical assumptions associated with the management strategy.

### 6.3. *Size, sex and season*

Use of these types of passive controls on the fishery, are fairly simple to implement initially.

- Size of the animals retained could initially be set at an acceptable market size (110 mm carapace width (CW)) or at values set in other jurisdictions (127 mm CW) until information on growth, molting patterns, mortality and pricing information are available to conduct specific yield per recruit assessments. Choosing the larger size that is consistent with Alaska is advantageous because escape tunnel information is available which could be incorporated into trap regulations, and reduce bycatch and handling of undersized crabs.

- A size limit set to prevent recruitment overfishing could be set at an arbitrary level, such as the size for 50% sexual maturity. To evaluate the size limit in this case and or prove its efficacy, one would require information as to the relative index of recruitment, and how that changed with a directed fishery and the size of 50% maturity.

- The time of year in which to fish needs to be tested to see what variations in product quality occur as a result of different seasons. Things to watch for, would be soft shelled animals and changes in availability of different sizes and sexes of animals. Precautionary guidelines can be established such as those in fisheries on *C. opilio*, which have been recommended to be closed when the proportion of soft-shelled crabs exceed 20%. In this case, an objective criteria of claw hardness of less than 68 on a durometer has been established to distinguish soft shell animals.

- Sex restrictions often depend on the market demand and size limits. Generally females are considerably smaller, and depending on the size limit, may not be available to the fishery. As mentioned above, there are concerns about the effects of a single sex fishery on the reproduction potential of the population. For this reason, data on the condition of the reproductive capacity of the multiparous female component of the population must be collected. Since this information would not readily be available through fishery dependent sampling, a fishery independent program must be developed.

### 6.4. *TACs*

Setting of TACs for the area is more complex in the requirements for determination of an appropriate harvest rate and biomass.

#### 6.4.1. Harvest rate

As mentioned previously, the harvest rate calculation may be taken from the natural mortality estimates (Table 2). The harvest rate is calculated as the maximum sustainable yield:

$$MSY = XMB_0$$

where: MSY is the maximum sustainable yield;
X is a scaling factor (common scaling factors that are often used include .2 (Garcia et al 1989), .4 (Caddy 1986) and .5 (Gulland 1971));
M is the instantaneous natural mortality rate;
and $B_0$ is the unfished biomass

We can now obtain a range of possible harvest rates depending on the age and the scaling factor chosen. The most conservative option is obtained by choosing the highest maximum age and the lowest scaling factor. This would indicate a moderately long lived animal with little compensatory capability. The type of data that would be required to determine an appropriate harvest rate may be obtained through length frequency analysis, in combination with measuring radionuclides activity ratios (Le Foll et al. 1989) used on possible terminal molt or skip molt shells.

Walters (1998) defines the target fishing mortality for year t in a developing fishery as $D(t)F_{opt}$ where D(t) is the progressive scaling factor.

#### 6.4.2. Biomass

To set a TAC for the area, however, we still require an estimate of $B_0$. Since this is a new fishery any estimate of biomass would be near $B_0$, as we must consider the trawl (idiot) bycatch, and the bycatch from the sablefish fishery. The resulting TAC would then be harvested annually. There are generally two ways of obtaining estimates of biomass either through fishery independent surveys or through the use of fishery dependent CPUE indices.

As mentioned previously, the fishery independent trawl survey is now the preferred source of information for all other major fisheries of this nature. Perry et al. (1998) summarizes the two approaches used in these surveys: the design-based approach, such as stratified random sampling and the model-based approach using systematic sampling patterns, and geostatistical techniques, such as kriging or bi-cubic spline interpolation (this latter technique forms the bases for the shrimp trawl surveys in British Columbia (Boutillier et al. 1996b). The final choice of survey design will depend on behaviour and distribution patterns of the animals, as we understand them at this time. Conducting adequate cost effective surveys will require extensive knowledge about the distribution and habitat preference of these animals. With over 6000 sq. km of potential habitat to cover, it will take a systematic approach to fishing to even be able to adequately design effective surveys. Hébert et al. (1997b) describe an exploratory fishery protocol for snow crab, which ensured that fishers put traps over the Laurentian Channel and the Magdelan Islands fishing area. Each fisher was requested to set an equal number of traps, with a minimum immersion of 18 hours, in designated quadrats systematically located over the entire fishing ground. Each quadrat was planned to be fished at least once (one hauling of traps per quadrat). Once the exploratory phase had been completed, fishers were free to fish anywhere in the zone.

If fishery-independent survey estimates are not available, then a fishery-dependent index would have to be established to monitored the rates of decline in CPUE. There are numerous problems with CPUE indices, which have already been mentioned. However, there are ways of better understanding a CPUE index and standardizing effective effort. Some of the necessary approaches that may have to be incorporated would include: standardized traps; keeping soak-times short and consistent (restricting the amount of gear to what can be handled in a day, short openings which do not allow gear to be left for long periods of time etc.); geo-referencing the set locations; proper logs (counts of animals as well as the weights of animals retained and discarded); at sea observer and biological coverage; and tagging studies designed to measure exploitation rates. In some restricted east coast area fisheries, it only takes two weeks of intensive fishing to see substantial declines (up to 60%) in CPUE (Biron et al. 1997).

However, Walters (1998) points out that when initially calculating catch ($C_t$), one should use a probability distribution ($B_c(t)$) for biomass that summarizes all the information for $B_t$ up to the time t, not just the most recent survey information. He points out that by using this strategy, the decision rule for catch,

$$C(t) = D(t)F_{opt}B_c(t)$$

is self adjusting, and as we get better information on biomass, $B_c(t)$ comes closer to the best biomass point estimate $B_{0.5}(t)$. He states that by using a constant decision rule that C<0.5 or the probability of C(t)/B(t) is greater than $D(t)F_{opt}$ , for year t <0.5, creates an economic incentive for gathering information that will narrow the B(t) distribution, and bring $B_c$ (t) closer to $B_{0.5}(t)$.

### 6.5. Target or reference point thresholds

Target spawner escapement thresholds are used in the management of fisheries such as prawns (*Pandalus platyceros*), and salmon fisheries. These fixed escapement targets are dependent on a stock recruitment relationship, where an index of spawners is set and the fishery closes when that level is reached. In the case of prawns, the index was initially set using fishery-independent indices from a fishery which had historically been able to maintain itself. These target levels have, and continue to be evaluated through experimental fishery manipulations to determine their adequacy, and to test their efficacy

(Boutillier 1993). This type of system has only successfully been implemented on semelparous animals. With the multiparous nature of Tanner crabs and the potential for larger variations in annual recruitment, it is unlikely that a system like this will work.

There is the possibility to use this index system to monitor other threshold based biological target or reference points. As Perry et al. (1998) point out, these systems are used to monitor fished populations and specific management actions are taken when thresholds are met. These thresholds may be range from a particular fishing mortality or exploitation rate to a fraction of the unfished biomass. In the former case this may be the annual target level in the latter case this may be the point at which no further fishing will occur until the stocks rebuild. FAO (1995), in their report on precautionary approach to fisheries cites under article 69 "Biological reference points for overfishing should be included as part of a precautionary approach". As discussed previously, $F_{opt}$ in a fully exploited population may be as high as .6M. However, in the fishing down stage of a fishery, the fixed exploitation rate may vary considerably, depending on the speed at which the population is able to respond with compensatory mechanisms, such as increased growth and reduced natural mortality. Considering the range of estimated M presented in Table 2, $F_{opt}$ would be in the range from .33 to .17. The only way of resolving the most appropriate range brings us back to the discussion presented above by Walters (1998) about the best investment of data (i.e. what is the development time, and how do we assure that we collect the information required in the time frame). Development time, in this case, has been defined by Walters (1998) as the progressive development function set to increase over time so that catch approaches $D(t)F_{opt}Bt$ which approaches $F_{opt}Bt$ such that $D(t)<=1$.

$$D(t) = (t/t_h)/[1+(t/t_h)]$$

where $t_h$ is the number of years until fish mortality rate would be allowed to reach $0.5F_{opt}$.

If $t_h$ is high, the result would be the "smooth" development of the fishery without overshooting the long term sustainable level of catch. This is critical when deciding on which data collection system we embark on. Do we go slow, with traditional data collection processes that will surely take a great deal longer to provide data to resolve the uncertainty problems, or do we go forward with the same speed as industry usually does, and develop and examine experimentally the most appropriate levels of $F_{opt}$?

Critical conservation threshold reference points may also vary considerably from as low as 25% for productive animals like herring and pollock (Quinn et al. 1990, Zheng et al. 1993), to 50% for geoduck of unfished population levels (Harbo et al. 1995). Considering the unknown implications of selective harvest on only a single component of the stock, and the likelihood that fishery data will not provide information on the health of the other stock components, a conservative critical threshold of 40%-50% is probably appropriate, until sufficient information is collected to prove otherwise.

### 6.6. *Area closures*

The establishment of large area closures during the development of a fishery is becoming more and more prevalent in fishery management for species that are not highly migratory. These closures limit the proportion of a stock exposed to fishing, and therefore may control exploitation rate. They may also prevent sudden collapses of populations that are subject to depensatory survival and fecundity as populations become small, "Allee effects" (Quinn et al. 1993). The key information needs in establishing these areas are the relative distribution and abundance of crabs in the area. These large area closures must include locations of good habitat and high abundance for the species being protected, and not just marginal areas. There must also be surveys over time to evaluate the unfished populations in conjunction with the fished population. There may be two alternatives for designing these areas: large areas that are self-sustaining (this requires knowledge of the species biology especially migration patterns and larval distribution), or a patchwork of smaller refuge areas that provide recruitment to fished areas.

### 6.7. *Other Management options*

Other issues that need to be addressed include by-catch reduction, handling mortality and other fishery-related mortality, such a ghost fishing. In this case, by-catch reduction standard management practices would include the use of escapement devices or devices to prevent entry of a particular size class. To address trap loss and ghost fishing issues, the requirement for traps to be fitted with appropriate sized rot panels is generally an accepted management tactic.

As mentioned previously, the inclusion of soft-shell thresholds is a strategy that is used in other jurisdictions, in conjunction with seasonal closures. In those cases, an objective criteria using a durometer reading are used to evaluate the soft-shelled condition.

## 7. "Every thing in moderation including moderation"

(Buddha's Little Instruction Book - Jack Kornfield)

The following suggestions are submitted as an action plan for fishery development, so that we do not repeat the mistakes of other fisheries.

### 7.1. *Prior to any fishery proceeding:*

The term "fishing for information" does not imply an open commercial fishery. "Fishing for information" is a very structured fishery which is undertaken to provide specific information. This should be considered a fishery based survey which may not necessarily be profitable. The long-term success or failure of this fishery may well be determined by the quality of the initial data collected from this component of the fishery.

The segment of the coast that is presently available to the fishery for *C. tanneri* lies between 400-900 m from 48° 24′ N to 54° 34′ N, which encompasses approximately 370.2 nautical miles of latitude and an area of 6,900 sq. km (This is broken down by statistical area and sub-area in Table 3).

A systematic survey of the entire length of the coast should be undertaken with the proponents, to establish the distribution and an index of relative density between areas. For the distributional survey, the coast would be divided up into a matrix, 3 minute latitude blocks and fished at five depth ranges: 400-500, 500-600, 600-700, 700-800 and 800-900. Each 3 minute block would constitute a one day survey. Therefore, the coast would be covered in approximately 122 fishing days. Individual trip length would likely be limited to 4 or 5 days of fishing, to facilitate landing of quality product (Jamieson et al. 1990). Each latitude/depth block of the survey matrix would be fished with a string of 40 standardized traps on an over night soak (200 traps per vessel). The standard traps would be something like a top loading stackable square or conical 53" pyramids. The traps would have all escape ports wired shut for the purposes of the survey.

Each vessel would be expected to carry an observer to conduct technical tasks associated with biological data gathering. Marketable crabs would be retained by the vessel for sale, and all others would be tagged and returned as close as possible to the area of capture. A survey area would be allocated to each vessel receiving a license to fish in the Phase 1 study. For example, if 10 vessels were licensed, then it would cost each of them 12 days of fishing time. The survey would be conducted as close as possible to the same period for all participants e.g. September 1998.

Detailed vessel logbooks should be mandatory during the distributional and biomass phases of the survey. Logbooks should contain accurate geo-referencing, depths and types of gear, soak or haul times, trap spacing, and baits. A record of all traps (or trawls) pulled should include species composition, number of discards by sex, number of crabs kept, and the total weight of landed crabs.

During the survey, biological information collected by observers should include detailed catch information on all species caught. For Tanner crabs, specific information should include: shell width; claw height measurements; sex; reproductive condition; shell condition (age); injury evaluation; and incidence of disease or parasitism. A subsample should be measured in greater detail, including: morphometric measurements; weight; evaluation of gonadal state; and an evaluation of intermolt state (via the mouth parts). Further laboratory analysis should include detailed morphometric measurements; microscopic evaluation of gonadal condition; estimation of fecundity; precise evaluation of intermolt state and shell age; and incidence of disease or infection.

### *7.2. After the survey*

The survey results on distribution and the index of relative density would then be used to divide the coast up into three zones: no fishing zone in 50% of the estimated habitat; fixed exploitation rate zone (based on conservative estimates of F and biomass) in 25% of the habitat; and experimental zones fished at various levels to test initial assumptions in 25% of the habitat. In the experimental fishing areas, the objective will be to test the response of the population to a fishery, and evaluate different management strategies.

Each of the different zones should be well represented along the length of the coast. The no fishing zones should be appropriately sized and located (from the distributional surveys) to act as functional population reserves. The no fishing zones should include areas identified as attractive to fishing exploitation that will act both as unfished reference points to compare with fished areas, and as biological refugia with the potential for rebuilding exploited stocks.

Once these no fishing, conservative harvest and experimental fishing zones are established, area swept trawl surveys should be conducted in representative areas of abundance. These surveys would provide the basis from which preliminary quotas can be established in fixed exploitation and experimental zones, and preliminary indices of abundance and dynamics of the stocks in all areas. Detailed logbooks of all fishing activities, as outlined in the previous section, will be required along with mandatory observer coverage for bycatch and tag recovery information. The use of vessel observers and logbook systems unique to this fishery would be preferable.

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**Table 1. Tanner Crab fisheries, management measures , stock assessment methods and present stock status.**

| Tanner Crab Species and Stock | Present Management Measures/System | Stock Assessment Methods | Stock Status |
|---|---|---|---|
| *C. opilio* - Newfoundland and Labrador | Size (95 mm CW); Sex(M); Area; Trap limits per vessel; quotas; IVQ's; dockside monitoring; management areas to control distribution of effort | Research surveys using traps and bottom trawls | Stable commercial catch rate in most areas; but area-specific inshore declines are predicted |
| *C. opilio* - Eastern Nova Scotia | Size (95 mm CW); Sex(M); Seasons; Soft-shell restriction; IBQ's | CPUE analysis from logbooks<br>Annual bottom trawls initiated in 1997 | Sustained good recruitment in late 1980s- early 1990s. Above average catch rates in all areas; Resource appears to be widely distributed; Evidence of good new recruitment |
| *C. opilio* - Southern Gulf of St. Lawrence | Size (95 mm CW); Sex(M); Seasons; Licence limitation; Trap limitation; soft-shelled closures; Quotas | Annual bottom trawl survey immediately following the fishery; Sampling the commercial catch | Continuing decline in commercial biomass since 1994; Recruitment to fishery expected to decline to 1999. New recruitment wave expected in near future. |
| *C. opilio* - Estuary & Northern Gulf of St. Lawrence | Size (95 mm CW); Sex(M); TACs; Trap limitation (150 Japanese traps/licence); White crab closures (@ 20%) | Bottom trawls and concurrent trap surveys; CPUE analysis | Continuing decline in CPUE, landings, and male sizes until 1998, when the next recruitment wave is expected to be reflected in 1999 fishery |
| *C. opilio* - Bering Sea /Aleutian Islands, Alaska | Size (78 mm CW); Sex(M); Trap restrictions; Seasons; Guideline Harvest Limit | NMFS bottom trawl surveys | 1997 NMFS trawl survey show increasing stocks, males (>101 mm CW) increased by 78% over 1996 |
| *C. bairdi* - Bering Sea /Aleutian Islands, Alaska | Size(140 mm CW); Sex (M); Trap restrictions; Seasons; Area restrictions; Guideline Harvest Levels | NMFS bottom trawls | Widely fluctuating abundance estimates and catches throughout 1980s & 1990s. Currently very low stocks shown by plummeting catches and NMFS trawl surveys show little chance of improvement. |
| *C. tanneri* - Westward Region Alaska | Size(127 mm CW); Sex (M); Trap restrictions:; Seasons; Area restrictions; Precautionary allowable harvest limits and specific area harvest limits; On-board observers; > 200 fm depths | Bottom trawls; On-board observers sampling commercial catch; CPUE analysis | Not Available |
| *C. angulatus* - Westward Region Alaska | Size(127 mm CW); Sex (M); Trap restrictions:; Seasons; Area restrictions; Precautionary allowable harvest limits and specific area harvest limits; On-board observers; > 200 fm depths | Bottom trawls; On-board observers sampling commercial catch; CPUE analysis | Not Available |
| *C. tanneri* - Oregon | Trap restrictions (Dungeness traps > 40 fm depths | | Not Available |

**Table 2. Age and calculated mortality rates from Hoenig (1983)**

| Age (years) | Mortality (M) |
|---|---|
| 8 | 0.55 |
| 10 | 0.44 |
| 12 | 0.37 |
| 14 | 0.32 |
| 16 | 0.28 |

**Table 3. Area of depths ranging from 400-900 m along the continental shelf, by Pacific Fisheries Management Statistical Area and sub-Area.**

| Statistical Area Number | Statistical Sub-Area Number | Area (sq. km) by Sub-Area | Total Area (sq. km) by Statistical Area |
|---|---|---|---|
| **101** | 1 | 141.56 | **695.73** |
| | 2 | 207.69 | |
| | 3 | 346.48 | |
| **142** | 1 | 459.68 | **1528.44** |
| | 2 | 1,068.71 | |
| **130** | 1 | 556.40 | **1088** |
| | 2 | 367.36 | |
| | 3 | 164.24 | |
| **102** | 2 | 110.08 | **392.72** |
| | | 282.64 | |
| **108** | 2 | 326.12 | **326.12** |
| **110** | 0 | 15.04 | **15.04** |
| **111** | 0 | 8.56 | |
| **127** | 2 | 358.20 | **639.68** |
| | 4 | 281.48 | |
| **126** | 2 | 682.28 | **845.45** |
| | 3 | 74.40 | |
| | 4 | 88.76 | |
| **125** | 4 | 27.76 | **463.36** |
| | 6 | 435.60 | |
| **124** | 1 | 188.0 | **878.80** |
| | 2 | 646.76 | |
| | 4 | 44.04 | |
| **Total all Areas** | | | **6881.90** |

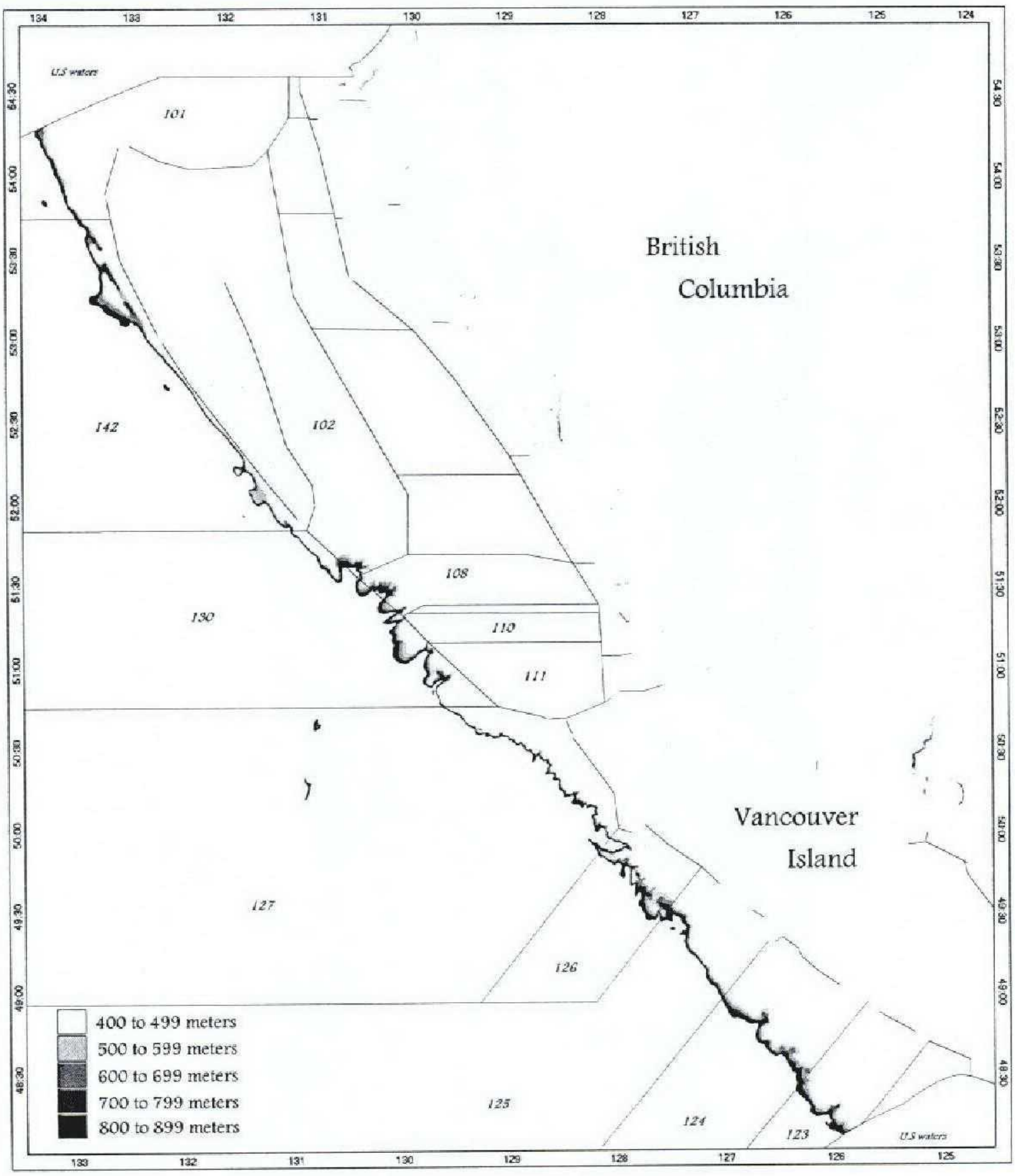


**Figure 1. Location of potential *Chionoecetes tanneri* and *C. angulatus* habitat on the continental shelf of British Columbia**

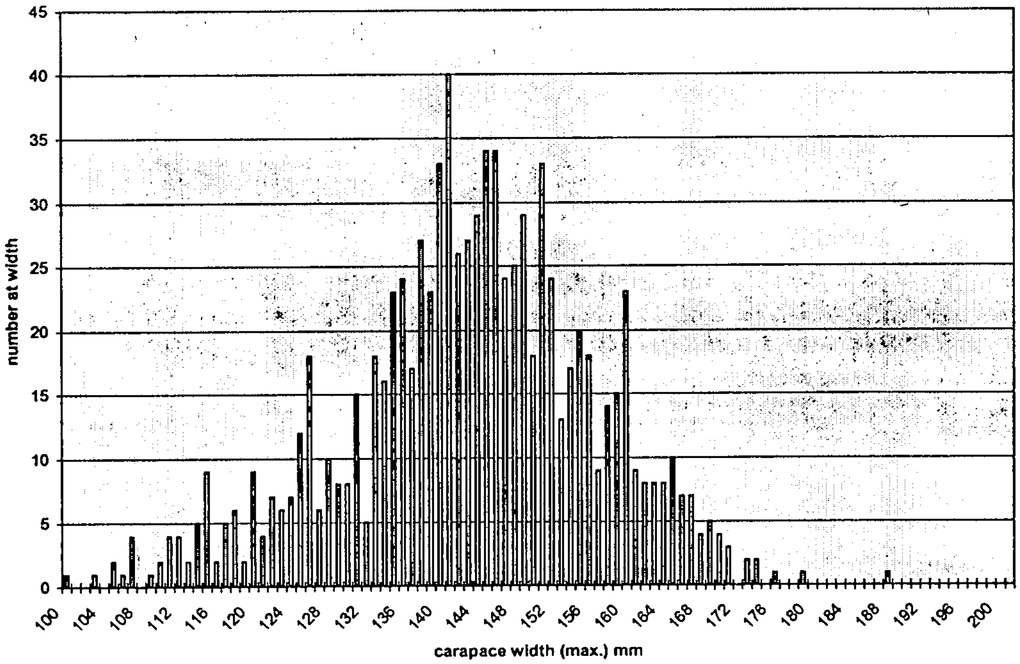


**Figure 2. Frequency distribution of *C. tanneri* maximum carapace width - from W.E. Ricker survey May 1988**