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Biological decision rules for the assessment and management of directed fisheries on *Pandalus hypsinotus*, Humpback Shrimp

Règles de décision biologique pour l'évaluation et la gestion des pêches dirigées de la crevette à front rayé (*Pandalus hypsinotus*)

J. S. Dunham, J. A. Boutillier, D. Rutherford, and K. Fong

Fisheries and Oceans Canada
Pacific Biological Station
Shellfish Stock Assessment Division
3190 Hammond Bay Road
Nanaimo, BC, V9T 6N7

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ABSTRACT

This paper examines options for assessing and managing recruitment overfishing in existing and new commercial humpback shrimp fisheries in BC. The biological parameters used in this review are based on a study of a humpback shrimp population in Drury Inlet that was surveyed by Shellfish StAD in November 2001 and March 2002 with trawl and trap fishing gear. In addition, bycatch issues associated with habitat and different gear types used in targeted fisheries are examined.

Aspects of humpback shrimp biology important in this review include estimates of age structure, sexual condition, fecundity, and natural mortality. The humpback shrimp population was composed of 3 age classes, approximately 32% of the shrimp being female. Mean fecundity was 880 eggs per female; however, larger, older female shrimp typically produced a greater number of eggs. Humpback shrimp experienced high natural mortality (mean M=2.0).

Significant variations in population structure estimates were observed depending on the type of fishing gear used. In general, trawl catches of humpback shrimp were more representative of the population, in terms of age and sexual condition, compared to trap catches, which were biased towards larger, older female shrimp. Trends in trap CPUE were more obvious when measuring numbers-at-age rather than weight of shrimp.

Using the information from the Drury Inlet pilot study, three options for assessing and managing recruitment overfishing in directed commercial humpback shrimp fisheries are discussed. These options include: 1) a fixed harvest rate model based on fishery independent shrimp biomass information, 2) a fixed harvest rate model based on fishery dependent CPUE information, and 3) a fixed escapement model based on egg production information.

It was concluded that the management option using a fixed harvest rate with fishery independent assessment procedures is appropriate for both trawl and trap fisheries. In contrast, options using a fixed harvest rate with fishery dependent biomass indices and fixed escapement are only appropriate for a trap fishery. Recommendations on the conservative decision rules associated with these management options are discussed, as well as variations in bycatch in the two fishing options. Recommendations were made on a process for determining humpback shrimp fishing areas where these assessment and management options should be implemented.

RÉSUMÉ

Ce document porte sur l'examen des options pour l'évaluation et la gestion de la surpêche du potentiel reproducteur imputable aux pêches commerciales existantes et nouvelles de la crevette à front rayé en Colombie-Britannique. Les paramètres biologiques utilisés dans cet examen proviennent d'une étude d'une population de crevette à front rayé du bras Drury faite par la Division de l'évaluation des stocks (mollusques et crustacés) en novembre 2001 et mars 2002, à partir de relevés au chalut et au casier. Enfin, les enjeux des prises accessoires reliés à l'habitat et aux différents types d'engins utilisés pour les pêches dirigées sont examinés.

Les aspects de la biologie de la crevette à front rayé qui sont importants aux fins du présent examen incluent les estimations de la structure d'âge, la maturité sexuelle, la fécondité et la mortalité naturelle. La population de crevettes à front rayé se composait de trois classes d'âge, dont environ 32 % étaient des femelles. La fécondité moyenne se situait à 880 oeufs par femelle, mais les grosses femelles plus âgées portaient un plus grand nombre d'œufs. Le taux de mortalité

naturelle était élevé (M moyen = 2,0).

Des variations significatives dans les estimations de la structure de la population ont été observées selon le type d'engin de pêche utilisé. En général, les prises au chalut étaient plus représentatives de la population en termes d'âge et de maturité sexuelle que les prises au casier, un engin prédisposé à la capture de grosses femelles plus âgées. Les tendances des PUE au casier étaient plus évidentes lorsque exprimées en nombre à l'âge plutôt qu'en poids des prises.

À partir de l'information provenant de l'étude pilote du bras Drury, trois options pour l'évaluation et la gestion de la surpêche du potentiel reproducteur imputable aux pêches commerciales dirigées de la crevette à front rayé sont examinées. Ces options incluent : 1) un modèle axé sur un taux d'exploitation fixe reposant sur des données de biomasse de crevette indépendantes de la pêche; 2) un modèle axé sur un taux d'exploitation fixe reposant sur des données de PUE dépendantes de la pêche; et 3) un modèle axé sur un taux d'échappement fixe reposant sur des données de production d'oeufs.

Il a été conclu que l'option de gestion utilisant un taux d'exploitation fixe et faisant appel à des procédures d'évaluation indépendantes de la pêche est appropriée pour les pêches au chalut et au casier. Par contre, les options reposant sur un taux d'exploitation fixe faisant appel à des indices de biomasse dépendants de la pêche et sur un taux d'échappement fixe ne sont appropriées que dans le cas de la pêche au casier. Les recommandations au sujet de règles de décision prudentes applicables à ces options sont discutées ainsi que les variations des prises accessoires associées à celles-ci. Des recommandations ont été formulées au sujet d'un processus d'identification des zones de pêche de la crevette à front rayé où ces options d'évaluation et de gestion devraient être mises en oeuvre.

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1.0 INTRODUCTION

There are in excess of 87 species of shrimp in British Columbia (BC) waters. Of these species, northern pink (*Pandalus borealis eous*), smooth pink (*P. jordani*), and sidestripe shrimp (*Pandalopsis dispar*) are harvested by a targeted trawl fishery and the spot prawn (*Pandalus platyceros*) is harvested by a targeted trap fishery. Assessment and management programs based on biological decision rules to prevent recruitment and growth overfishing are in place for these fisheries. Recruitment overfishing in the shrimp trawl fishery is managed with a fixed harvest rate model based on fishery independent estimates of shrimp biomass. Recruitment overfishing in the prawn fishery is managed using a fixed escapement model commonly referred to as a spawner index. Growth overfishing in the shrimp trawl fishery is not controlled, although some of the industry is reporting using larger mesh to target larger shrimp species and older age classes. Growth overfishing in the prawn fishery is controlled through a combination of size limits, trap escapement modifications, and manipulation of the fishing season (Boutillier and Bond 2000).

Humpback shrimp (*Pandalus hypsinotus*) were, until approximately seven years ago, generally harvested as bycatch in commercial shrimp trawl and trap fisheries. However, as new markets developed, including the more lucrative live market, harvest of this shrimp species has increased as commercial fishers began targeting isolated populations. Assessment and management of humpback shrimp stocks are still in developmental phases and have not kept pace with the rapidly expanding targeted fisheries. As a result, the Minister of Fisheries and Oceans put a ban on further expansion of directed fisheries for humpback shrimp until an assessment and management framework was established.

In 1999, a PSARC (Pacific Scientific Advice Review Committee) paper titled "*Pandalus hypsinotus*, humpback shrimp: a review of the biology and a recommended assessment framework for a directed fishery" (Boutillier and Nguyen 1999) included a review of the biology and world fisheries for humpback shrimp and outlined a number of assessment and management options for directed fisheries. However, specific advice on biological decision rules for assessing and managing directed humpback shrimp fisheries in BC waters was beyond the scope of the paper. In 2001, fisheries managers and industry requested "…a need to develop a sound biological basis for the management of humpback fisheries before targeted fisheries develop further" (Appendix 1). This paper was prepared in response to this request.

This paper provides biological decision rules for three methods to assess and manage recruitment overfishing in directed humpback shrimp fisheries in BC, and discusses their assumptions and data requirements. It presents the results from a pilot study which was conducted to estimate the biological parameters and fishery dependent impacts on targeted fisheries for humpback shrimp. This pilot study was initially planned to monitor directed trawl and trap fisheries on an isolated, relatively unexploited[1] population of humpback shrimp. In addition to the fisheries, two fishery independent pre and post assessments of the shrimp population were planned (approximately four months apart). These results are discussed in context with each of the assessment and management options and provide biologically-based decision rules which should be used for directed fisheries for humpback shrimp. Comparisons were also made of the bycatch collected by the two types of fishing gear used in the pilot study. In addition, a process was proposed for identifying areas where directed humpback fisheries occur which should be included with the assessment and management options.

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[1] The commercial exploitation history of shrimp in Drury Inlet is detailed in Appendix 2.

1.1 ASSESSMENT AND MANAGEMENT OPTIONS

Three management options that are discussed in this paper include:

- a fishing mortality rate applied against an estimate of shrimp biomass to provide a catch quota;
- a fishing mortality rate monitored against a fishery dependent CPUE index;
- a fixed escapement rate monitored against a fishery dependent CPUE index.

1.1.1 Fishing Mortality Rates

Using a harvest rate management strategy requires the following information: 1) an appropriate harvest rate, and 2) an index of stock abundance against which the harvest rate is applied. Harvest rates currently used in the commercial shrimp trawl fishery range from 25-33% of the estimated biomass as determined from fishery independent surveys. These harvest rates were established using historical proxies (after Gulland 1971) of appropriate fishing mortalities as they relate to the natural mortality of the animals being harvested. Martell *et al*. (2000) recommended using a 35% harvest rate on the abundance of shrimp in excess of a minimal biomass limit for the offshore pink shrimp trawl fishery on the west coast of Vancouver Island. Martell's analysis was based on stock reconstruction and VPA modeling of the shrimp population. This analysis included information from fishery independent surveys and catch-at-age information from the commercial fishery.

If the shrimp abundance estimate is derived before the fishery, then a manager can apply a catch ceiling. If there is no pre-season abundance index, then an in-season monitoring system must be implemented that monitors a fishery dependent index that tracks the same trends as population abundance trends.

1.1.2 Fishery Independent Data (Using Pre-Season Shrimp Biomass Estimates)

In this management option, a pre-season catch quota would be derived from applying a specific harvest rate to an estimate of shrimp biomass obtained from a fishery independent survey of the population. The biomass of shrimp in an area or for a particular stock should be determined using a survey that determines the biomass in both trawlable and untrawlable regions. Survey results can be used to index the relative stock biomass and demographics of the population, and can provide estimates of total biomass and age-class indices. Catch quotas can then be established by applying a harvest rate against the portion of the stock that is targeted by the commercial fishery. The fishery would then have to be monitored to establish when the quota is reached.

A depletion estimation procedure is a technique that examines how measured removals of shrimp influence the relative abundance indices (e.g., CPUE or survey biomass index). The depletion estimate requires pre and post fishery abundance surveys and accurate estimates of fishery mortalities. The results of these depletion experiments would then be used to "calibrate" relative abundance indices to an absolute abundance estimate (Boutillier and Bond 1999).

1.1.3 Fishery Dependent Data (Using CPUE as an Index of Relative Abundance)

In this management option, an in-season monitoring system would be established which monitors harvest rate decision rules against a fishery dependent abundance index (CPUE) that tracks changes in the total population. The decision rules for a given point of time need to be modeled using CPUE data collected at the beginning of the fishery and applying an estimate of the total mortality rate of the shrimp stock in a manner that distinguishes between declines due to natural and fishing mortalities.

1.1.4 Fixed Escapement Model – Egg Production Index

This management option is a variation on the fixed escapement model used in the prawn fishery in BC. The purpose of an escapement index is to ensure that an adequate number of female shrimp evade capture or other fishing induced mortality such that, after all forms of mortality are considered, enough females survive to successfully produce sufficient offspring to sustain the population. The prawn trap fishery has been successfully managed using an index of female spawners since 1979. This management system was developed based on empirical data collected from a series of assessment cruises carried out in the early to mid-1970's in Knight and Kingcome Inlets (Boutillier 1988a,b) and has been modified to reflect a better understanding of the stock/recruitment relationship (Boutillier and Bond 1999).

Developing a spawner index based on a spawner/recruit relationship requires establishing a relationship between the number of spawners and the resulting recruitment. To establish this relationship, data need to be collected over a wide range of population sizes. Fixed escapement targets based on the number of spawners is relatively easily applied to animals with a semelparous life history (i.e., they spawn once and die). However, humpback shrimp are multiparous (i.e., they can spawn more than once) so the spawner escapement target is confounded by large variations in fecundity. Fecundity is a special problem for developing a fixed escapement index for humpback shrimp because of their ability to skip the male phase to become small-sized primary females. Primary females are not as fecund as larger older females; therefore, basing an escapement index on counts of females alone, as is done with prawns, would not be appropriate. A more complex escapement index based on egg production by size and age of spawners has to be developed.

In this option, the decision rules are based on a static percentage of maximum spawning (eggs) per recruit. The information required to calculate these decision rules include: the CPUE of female spawners from an unfished population, in-season CPUE measurements of female spawners in the fished population, size and age compositions of the female spawners, the natural mortality rates by cohort which will be used to determine spawner indices for the months up to the March/April hatching period, and the number of eggs per mature female by size and age.

Our goal when developing decision rules based on a percentage of the maximum egg production index for a humpback shrimp population was to leave alive in March (at the time of egg hatching) the appropriate number of female shrimp that would hatch a fixed percentage of the maximum potential number of eggs. But setting a fixed percentage is very difficult when you have no data - we do know from the literature (Clark and Anthony 1981) that at the time of the Gulf of Maine shrimp collapse the stock was <10% of it's maximum spawning potential. In fisheries where this type of decision rule has been implemented, the initial percent that defines overfishing is usually arbitrary. In a review by Zheng et al (1993), it was suggested that an acceptable fixed percentage ranged from 20% to 30%, where spawning potential was measured in terms of spawning biomass. There are, however, wide variations in this estimate with the percentage for some animals like the Atlantic greater amberjack (*Seriola dumerili*) being as high as 51-79% (Manooch and Potts 1997).

1.2 PILOT STUDY

1.2.1 Study Outline

To refine assessment and management options available for humpback shrimp fisheries, the Shellfish Stock Assessment Division (StAD), of the Department of Fisheries and Oceans (DFO), developed a pilot study which was conducted to estimate the critical biological and fishery parameters required in the management options outlined above. The study was initially designed to have an experimental fishery conducted between pre and post fishery independent surveys of a humpback shrimp population. Unfortunately, the commercial trawl and trap fishing was short-lived in the experimental area, as industry became quickly disinterested in the small size of shrimp available at that time. Nevertheless, Shellfish StAD was able to conduct two fishery independent surveys approximately four months apart on a humpback shrimp population.

1.2.2 Study Site

The population of humpback shrimp chosen for this study inhabit Drury Inlet, located NE from Port Hardy across Queen Charlotte Strait on BC’s mainland coast (lat. 50°54’14, long. 127°01’64) (Fig. 1). Drury Inlet is approximately 21 km long and 3.2 km wide, the upper portion of the inlet, Actaeon Sound, is 14 km long. Maximum depth is 101 m.

Drury Inlet was selected as the site for this pilot study because commercial humpback shrimp fishing has occurred here in the past, and does occur here presently, both trawl and trap fishing gear could be deployed, and Shellfish StAD has historic shrimp stock abundance information from the area.

1.3 BYCATCH

Bycatch is an issue in both commercial shrimp trawl and trap fisheries. Bycatch in the trawl fishery is being addressed through the use of grates and soft panels (industry recommended mandatory requirements for these in all trawls which was implemented in the 2000-fishing plan). These grates and panels sort the catch while the trawl is on the bottom, but there is no information on the survival rate of animals that are released, including fishery-related mortality of juvenile shrimp. The grates are very effective in eliminating larger fish, but their effectiveness in eliminating small fish seems to be a function of the type of trawl used. Otter trawls, which are towed at greater speeds, have significantly higher catch rates of small fish than do beam trawls. Industry has been working to rectify this problem through the use of rigid, hard-mesh panels in the head of the trawl. This was implemented in 2001 in all otter trawls at the request of the industry.

Bycatch in the trap fishery is restricted to those animals that can enter small tunnels and not escape through the mesh. In the prawn trap fishery, mesh size restrictions for the traps and tunnels improve sorting of undersized prawns on the bottom. All catches must be sorted immediately when traps are recovered to vessels and undersized prawns, egged prawns and bycatch must be released unharmed. In addition, gear can only be hauled once each day to limit the handling of prawns.

Bycatch in the pilot study was only measured in survey catches as the experimental commercial trap and trawl fisheries did not develop as planned. Bycatch was measured in terms of species and numbers of animals, categorized by the type of fishing gear used, mesh size, and type of benthic habitat where fishing gear were deployed. How bycatch varies in these situations is important when attempting to understand the need to manage humpback shrimp fisheries using an ecosystem-based approach.

1.4 COMMERCIAL HUMPBACK SHRIMP FISHING AREAS

As commercial fishers increase their targeting on humpback shrimp stocks throughout BC, areas or particular stocks of shrimp need to be identified in order for them to be managed effectively for recruitment overfishing.

2.0 METHODS

2.1 CAPTURE METHODS

Surveys were conducted using both trawl and trap fishing techniques. Substrate type and accessibility dictated the capture method employed. Accordingly, Drury Inlet was divided into two areas, "trawlable" and "untrawlable". The trawlable area was defined as the portion of the inlet that was accessible to the trawl vessel and where depth exceeded 50 m. The untrawlable area was defined as near-shore areas from the shoreline to a depth of 50 m and portions of the inlet inaccessible to the trawl vessel. Trawl and trap sampling occurred at two intervals spaced four months apart. The first sampling interval occurred November 17 - 19, 2001, the second interval occurred March 15-17, 2002.

2.1.1 Capture by Trawl

Trawl sampling was conducted from the 25 m Canadian Coast Guard Fisheries Research Vessel "Neocaligus". This vessel was equipped with a 17.7 m high-rise otter trawl and 1.7 m combination trawl doors. Trawl gear specifications include 58' head and foot ropes, a 12' rise, and a 1.5" poly mesh net with a 0.25" liner in the codend. A Nordmore separator grate (fish exclusion device) was used to reduce bycatch.

Tow locations were predetermined using a systematic sampling design. Trawl sampling occurred in the trawlable area only. In November 2001 and March 2002, 6 sites were trawled twice, for a total of 12 tows each month (Fig. 1). Tow times were 20 minutes, except 4 tows where times were approximately 15 minutes in length.

Total catch from each trawl was weighed to the nearest 0.1 kg. A subsample of the catch from each trawl was randomly selected and all species separated and weighed. Species-specific catch weights were determined by applying the species ratio in the sub-sample to the total weight in the trawl catch. Species occurring in low abundance (less than 0.05 kg) were recorded as "trace" amounts. One-half or one kilogram of humpback and spiny pink shrimp from each tow were counted to determine the number of shrimp per kilogram. Approximately 100 humpback and spiny pink shrimp were retained from each tow for length frequency (LF) analysis.

2.1.2 Capture by Trap

Trap sampling occured in both trawlable and untrawlable areas. Traps were deployed either from the Neocaligus or from a small 8 m skiff. All traps were plastic coated stainless steel, cone stacking, three ring frame traps with a 25" top diameter, 30" bottom diameter, and 12" high. All traps had three tunnels. Three different mesh sizes were used. The small mesh (SM) trap was fitted with 5/8" - 3/4" knotless black web; the medium mesh (MM) trap was fitted with 3/4" - 1 1/8" (about 1/2" × 1/2") nylon web; and the large mesh (LM) trap was fitted with 1 1/2" (3/4" ×

3/4”) nylon web. The SM trap is a shrimp research trap, the MM trap is a prawn research trap, and the LM trap is a commercially available prawn trap.

A total of twelve traps were fished on a single ground line. Each twelve trap set consisted of 4 traps of each mesh size alternated along the length of the ground line. The trap type attached to the start of a string was assigned randomly in order to negate any affects on catchability for traps being located first and last on a ground line. Traps were baited with cat food grade canned tuna. Baits were replaced after each trap soak. Trap sets were soaked overnight for 16-25 hours.

In November 2001 and March 2002, 29 trap strings were deployed each month throughout Drury Inlet. Twelve trap strings were set at tow locations (6 sites, 2 replicates), 7 trap strings were set in untrawlable areas near tow locations, 5 trap strings were set in other areas of Drury Inlet, and 5 trap strings were set in the upper reaches of the inlet (Fig. 1).

For each trap catch, humpback shrimp were sorted from other species, individually sexed and total numbers determined for each sex stage, and total shrimp weight determined. Shrimp for LF analysis were collected for each trap type on every string. For MM and SM trap models, which collected numerous humpback shrimp because of their smaller mesh sizes, approximately 35-40 shrimp were retained per string for LF analysis. For the LM trap model, all shrimp in each trap were retained for LF analysis. Bycatch (species other than humpback shrimp) was pooled by string and trap type (i.e., the 4 traps of each particular model type were combined per string), and species separated, counted, and weighed. Species occurring in low abundance (less than 0.05 kg) were recorded as “trace” amounts.

2.2 BIOLOGICAL SAMPLING

2.2.1 Age

Carapace lengths of humpback shrimp was measured using electronic calipers. Age composition of a “sample” was determined using length frequency (LF) modal analysis (Schnute and Fournier 1980). A minimum of 1,000 shrimp was included in each sample for LF analysis.

2.2.2 Sex

Sex of humpback shrimp was determined by examining the endopods of the first and second pleopods (see Butler 1980). Sex was recorded as immature, male, transitional, female, ovigerous female, or spent female.

2.2.3 Fecundity

Female humpback shrimp carrying eggs were randomly collected in March 2002 from the retained trawl and trap samples. Thirty humpback shrimp, stratified by size, were selected to determine fecundity. The egg mass from each individual was slightly thawed and then teased apart with tweezers and the eggs visually counted.

2.3 BIOMASS ESTIMATION

Geo-referenced modeling of the systematic survey data was used to estimate humpback shrimp biomass in Drury Inlet. For the biomass estimation procedure, we used the previously described “trawlable” and “untrawlable” area divisions. Estimates of biomass were calculated independently for each of the two areas and then summed to provide an overall estimate of humpback shrimp biomass in Drury Inlet.

Within the trawlable area, spatial analysis was used to estimate humpback shrimp biomass based on catch densities determined from trawl and trap catches. The surface area of the inlet was divided into grid blocks each with an area of 0.25 square nautical miles. Catch densities from each of the systematically placed tows were determined and the weight density information from each sample tow was assigned to the grid block where the centre point of the tow occurred. Some sections within the trawlable area could not be sampled with trawl gear because the substrate was rocky or there was an abundance of debris on the sea floor. Estimates of density in these sections were determined using traps. Trap catch rates were equated to trawl density by placing control traps next to trawl locations. This trawl catch / trap catch relationship was used to estimate a weight density at each of the trap locations and this density was applied to the appropriate grid block. This same method was also used to apply a weight density to grid blocks located just outside the trawlable area where trap catch data were available. A sector geospatial interpolation was then used to calculate values for the unsampled grid blocks within the trawlable area. The sector interpolation examined an area within a circle with a radius of ten grid blocks, with the target grid block (the block for which the value was being calculated) in the centre of the circle. The circle was divided into six sectors, and the value for the target grid block was estimated using a distance-weighted average of the nearest sample in each of the sectors. Thus, samples closer to the target grid block had a greater influence on the interpolated value. Once blank grid blocks were filled with an interpolated value, the index of biomass for the entire trawlable area was calculated by summing the values of each grid block. This spatial analysis was done using the CompuGrid GIS software package.

Within the untrawlable area which was sampled using traps only, shrimp biomass was estimated based on the average catch per trap. The trawl catch / trap catch relationship previously determined in the trawlable area was used to estimate shrimp density at each of the trap locations in the untrawlable area. The estimated density from each of the trap locations was then averaged and multiplied by the surface area of the untrawlable area to provide an estimate of humpback shrimp biomass in the untrawlable area of the inlet.

2.4 NATURAL MORTALITY RATE ESTIMATION

To calculate estimates of the natural mortality rate (M) for humpback shrimp in Drury Inlet, three sources of data were used as indices of changes in abundance over the four month period: 1) MM and SM trap CPUE of ages 3+ humpback shrimp, 2) MM and SM trap CPUE of female humpback shrimp (including ovigerous and spent individuals), and 3) the number of ages 3+ animals determined by the biomass estimation procedure. Gulland's (1983) estimation procedure for Z was applied using the following equation:

$$Z = -(12 / (t2 - t1)) \times \mathrm{Ln} (n2 / n1)$$

where:

t1, t2 are sampling times in months

n1, n2 are trap CPUE or ages 3+ shrimp density estimates determined at two points in time.

For this application, we assumed that Z=M because fishing mortality (F) in Drury Inlet was close to zero.

2.5 BYCATCH

The research vessel we used in Drury Inlet had an otter trawl with an exclusion grate attached which limited the numbers and sizes of bycatch species collected by the trawl gear. Total catch from each trawl was weighed. A sub-sample of the catch from each trawl was randomly selected and bycatch species separated, counted, and weighed. These measures were extrapolated to the remainder of the catch.

Bycatch species were grouped for trap type (i.e., the 4 traps of each particular model type were combined per string), and species separated, counted, and weighed. Bycatch was collected in trawlable areas and untrawlable rocky areas and compared. Bycatch was also compared between traps with different mesh sizes. Trap catches in all habitat types throughout Drury Inlet were aggregated by trap type for analyses and standardized for the number of traps used. Bycatch collected from trap and trawl gear were also compared.

2.6 COMMERCIAL HUMPBACK SHRIMP FISHING AREAS

To determine where commercial humpback shrimp fishing occurred in BC in the past, the DFO's commercial logbook database was analyzed. Records where humpback shrimp catches were greater than those of any other shrimp species were assumed to indicate that targeted fishing had occurred. Records where humpback shrimp catches were less than those of other shrimp species were not used for analyses – humpback shrimp harvested in these areas were assumed to be bycatch and not targeted. Only subareas where over 1,000 kg of humpback shrimp were removed via targeted fishing during the 2001/02 fishing season have been tabulated.

3.0 RESULTS

3.1 SELECTIVITY OF CAPTURE METHODS

Both trawl and trap fishing gear were used to collect humpback shrimp in Drury Inlet. In addition, traps with three different mesh sizes were fished. These different types and variants of fishing gear did not collect shrimp in the same manner, with regards to numbers, sizes, ages and sexual stages.

In general, the SM and MM traps caught more humpback shrimp than LM traps and the average size of shrimp captured in the SM and MM traps was smaller (Fig. 2). In November 2001, the increase in numbers of shrimp in the SM and MM traps was primarily due to larger non-egged females and smaller males (Table 1). We observed shrimp falling through the mesh of LM traps as they were hauled to the surface.

Similarly, in March 2002, the SM and MM traps collected more shrimp per trap than the LM trap (Table 2). Most shrimp collected in March were egged females and the SM and MM models collected similar numbers, whereas the LM model collected very few of these individuals. The SM trap caught more small male and transitional shrimp compared to the MM and LM models.

Sex composition of humpback shrimp in trawl catches was similar during the two sampling periods (Fig. 3). This consistency was not observed in trap catches. Even SM traps caught larger humpback shrimp than trawl gear did from the same habitat type (i.e., trawlable areas), especially in November 2001 (Figs. 4, 5). In November, trap gear caught a high proportion of larger female shrimp (non-egged) and a corresponding low proportion of male shrimp compared to trawl gear (Fig. 6). Similarly, in March 2002, the catches from trap gear showed higher proportions of female shrimp (non-egged, egged and spent) and lower proportions of male and transitional shrimp (Fig. 7) in comparison to trawl catches.

Trap CPUE estimates were sensitive to the metric that was applied. For example, trap CPUE estimates for age (Tables 3, 4, 5) and sex ratio (Tables 6, 7, 8) characteristics changed between November and March surveys, whereas estimates for weight were constant over this time period (Table 9).

3.2 BIOLOGICAL SAMPLING

3.2.1 Age

Biological data determined from humpback shrimp collected by trawl gear were considered to be the most representative of the population because trawl catches were less selective than trap catches. The age structure of the humpback shrimp population in Drury Inlet was similar in November 2001 and March 2002 (Fig. 8). The largest component of the population was age 1 individuals (58% in November, 66% in March); large-sized ages 3+ shrimp constituted only a small component of the population (8% in November, 3% in March; Table 10, Fig. 8).

The relationship between shrimp age and size is depicted using the von Bertalanffy growth model (Fig. 9, Table 10). Humpback shrimp increased in size during the sampling intervals (Table 11). Age 0 shrimp increased in size the most during the four month period; ages 1 and 2 shrimp increased in size approximately the same amount. Size change in ages 3+ shrimp was minimal between November and March – this is to be expected since ages 3+ animals are females and they will not molt while they are carrying eggs. The somatic growth measured during this time period should not be considered representative of the growth over the entire year because somatic growth for shrimp is known to be greatest in the spring and summer, while in the fall and winter periods energy is generally directed to reproductive growth.

3.2.2 Sex

Approximately 32% of the trawl sampled humpback shrimp population at both time periods were female (Fig. 3). In November 2001, 100% of the female shrimp sampled (32.1% of the population) were not carrying eggs. Four months later in March, the sampled shrimp population was composed of 5.7% females that were not carrying eggs, 24% were egged, and 2.3% had already released their eggs. In November, 68% of the population were either males or transitionals, with most (67.6%) being males. By March, 24.9% of the population was in the transitional state.

3.2.3 Fecundity

The mean carapace length of female humpback shrimp examined (n=30) was 23.6 ± 2.6 mm and the mean fecundity per individual was 880 ± 395 eggs. The number of eggs produced per individual ranged from 153 to 1,897. The smallest female whose eggs were counted had a carapace 19.5 mm, the largest female had a carapace 27.9 mm in length. A linear trend line best describes the relationship between female shrimp size and numbers of eggs produced by an individual (Fig. 10). Larger females typically produced more eggs than smaller females. Only 39% of the variation in the number of eggs produced by females is accounted for by size.

The mean number of eggs produced per individual in each age class was highest for age 3 shrimp (1,141 eggs) (Table 12). Approximately 90% of the age 3 shrimp carried eggs, compared to 61%

of the age 2, and 1.3% of the age 1 shrimp. Thus, most eggs were produced by shrimp ages 2 and 3 years old, with 5-6 times more eggs being produced by age 2 rather than age 3 females. Total egg production in Drury Inlet was 1.69×10^9 eggs.

We modeled the relationship between female size and number of eggs produced per individual. The linear relationship depicted in Fig. 10 is described by the equation:

$$y = 95.048\,x - 1367.9$$

where:

y is the number of eggs per female shrimp

x is female shrimp carapace length (mm).

3.3 BIOMASS ESTIMATION

Humpback shrimp biomass estimated using spatial analysis for the trawlable area was slightly lower in November 2001 (24.3 tons) compared to March 2002 (28.9 tons) (Table 13). However, in the untrawlable area, biomass dramatically increased in March (52.5 tons) compared to November (19.5 tons). This resulted in a much higher humpback shrimp biomass estimate for the entire inlet in March (81.4 tons) compared to November (43.8 tons). Although trap catches cannot be used to estimate biomass directly, CPUE estimates derived using standardized SM trap catches were used to index changes in humpback shrimp abundance. CPUE estimates remained relatively unchanged in the trawlable area in November and March, but increased in rocky areas and the upper inlet in March (Table 14).

Decreases in the numbers of female and ages 3+ shrimp were observed from the November to the March sampling period (Table 15). These decreases were attributed to natural mortality.

Variability is inherent when measuring shrimp biomass regardless whether replicate tows are performed 2 days or 4 months apart. Regarding shrimp biomass collected in trawls performed in the same location 2 or 3 days apart, variance was exceptionally high in 25% of the replicate tows, meaning that large differences in humpback shrimp biomass were estimated to exist between the first and replicate tow (Table 16). For example in November, the initial tow at site #6 caught 84 kg of humpback shrimp, whereas the replicate tow collected only 6 kg. In addition, shrimp catches collected 2 or 3 days apart were generally lower in the replicate tows; however, in one instance in March the replicate tow (54 kg) caught more shrimp than the first tow (21 kg). Regarding replicate tows performed 4 months apart at the same locations, the average biomass of humpback shrimp collected was lower in March than in November at 83% of the sites.

3.4 NATURAL MORTALITY RATE ESTIMATION

Estimates of the Drury Inlet humpback shrimp natural mortality rate (M) range from 0.97 to 3.42, depending on the abundance index used (Table 17). The average mortality based on using the five different indices of abundance was 2.0. This natural mortality rate is equivalent to an annual survival rate of 14%.

3.5 BYCATCH

3.5.1 Trawl Gear

In November 2001, trawl gear collected 1,846 kg of marine biomass, of which 1,418 kg or 77% was bycatch (not humpback shrimp). Spiny pink shrimp (24.5%), eelpouts (23.3%) and shiner perch (16.0%) comprised 63.8% of the total catch (Fig. 11). In March 2002, trawl gear collected 1,356 kg of marine biomass, of which 1,051 kg or 78% was bycatch. Shiner perch (26.3%), spiny pink shrimp (16.5%), eelpouts (13.3%) and Pacific herring (8.7%) comprised 64.8% of the total catch.

Of the commercial shrimp species collected in Drury Inlet with trawl gear, spiny pink shrimp were the most abundant (24.5 and 16.5% of the total catch in November and March respectively)(Fig. 11). Prawns, sidestripe, coonstripe, and flexed shrimp combined represented approximately 1% of the total catches during both sampling periods.

Bycatch species composition in trawl catches changed at different sampling periods. Higher proportions of spiny pink shrimp and eelpouts were collected in November compared to March (Fig. 11). In contrast, higher proportions of shiner perch and herring were collected in March. Trawl bycatch species that contributed less than 1% of the total catches are listed in Table 18.

3.5.2 Trap Gear

Trawlable areas

In November 2001, in trawlable areas of Drury Inlet, trap gear collected 189 kg of marine biomass, of which 93 kg or 49% was bycatch (not humpback shrimp). Sea stars (29.1%) and red rock crabs (10.4%) represented 39.5% of the total catch (Fig. 12). In March 2002, trap gear collected 198 kg of marine biomass, of which 122 kg or 62% was bycatch. Sea stars (35.8%) and red rock crabs (12.1%) represented 47.9% of the total catch.

Of the commercial shrimp species collected, prawns, spiny pink, flexed, and coonstripe shrimp represented approximately 1% of the catch during November. Prawns represented about 4%, and the other shrimp species less than 1% of the catch during March. Trap bycatch species that contributed less than 1% of the total catches are listed in Table 19.

Rocky areas

In November 2001, in rocky areas throughout Drury Inlet, trap gear collected 225 kg of marine biomass, of which 196 kg or 87% was bycatch. Sunflower starfish (33.1%), red rock crabs (30.9%), and graceful crabs (11.8%) represented 75.8% of the total catch (Fig. 13). In March 2002, trap gear collected 191 kg of marine biomass, of which 156 kg or 82% was bycatch. Sunflower starfish (46.5%), prawns (14.1%), red rock crabs (9.3%), and graceful crabs (5.9%) represented 75.8% of the total catch.

Of the commercial shrimp species collected, prawns constituted 6% and 14% (November and March respectively) of the catch. Coonstripe, flexed, and spiny pink shrimp combined represented less than 1.4% of the catch during both months.

A much higher proportion of red rock crabs was collected in November (30.9%) compared to March (9.3%) (Fig. 13). Higher proportions of starfish and prawns were collected in March.

Comparison of trap bycatch in trawlable and rocky areas

More bycatch was caught in traps deployed in rocky (84.5% of total catch) than trawlable (55.5%) areas. Starfish and red rock crabs were the main bycatch species collected in both habitat types. Graceful crabs and prawns, although caught in both habitat types, were more prevalent in rocky areas. Catches of red rock crabs varied in rocky areas between November and March – this variability in red rock crab catches between time periods was not observed in trawlable areas.

By trap type

SM traps collected the highest number of different species (mean = 21), MM traps an intermediate number (mean = 20), and LM traps the fewest species (mean = 17) (Table 20). SM traps collected more shrimp in terms of numbers and species, especially the smaller species like eualids, flexed pink shrimp, crangons, and argids (Fig. 14, Table 20). MM traps collected more crabs than other trap types, especially red rock and graceful crabs (Fig. 14). Although 12 species of fish were collected in all trap types (Table 21), the number of fish collected in traps was generally low. The highest number of individual fish collected by a particular trap type for all strings deployed was 6 Pacific staghorn sculpins in the MM trap type in November.

Traps caught fewer crabs in March compared to November (Fig. 14). More prawns were collected in March. Much fewer coonstripe shrimp, eualids, and flexed shrimp were collected in traps in March.

3.5.3 Trawl vs Trap Gear

The proportion of bycatch was greater for trawl (77.5%) than trap (55.5%) gear. These two types of fishing gear collected different organisms – trawl gear collected mainly spiny pink shrimp, eelpouts, shiner perch, and herring, whereas trap gear collected mainly starfish and red rock crabs.

Overall, trawl gear collected many more bycatch species than trap gear (Table 22). Trawl gear caught 10 more species of fish than trap gear. In contrast, trap gear collected more species of crabs and starfish than trawl gear. Both types of fishing gear caught a similar number of shrimp species. Although the survival of released non-target species from traps is unknown, the condition of animals returned to the water captured by trap gear was much better than those captured by trawl gear.

3.6 COMMERCIAL HUMPBACK SHRIMP FISHING AREAS

3.6.1 Trawl Fishery

Targeted fishing of humpback shrimp occurred in at least 8 subareas. Very large fishing effort occurred in Subareas 4-9 and 12-39 (Table 23). The largest amount of humpback shrimp biomass was removed from Subarea 4-9. CPUE was highest in Subareas 6-23 and 5-5 and lowest in 12-39 and 13-24.

3.6.2 Trap Fishery

Currently, a directed fishery for humpback shrimp occurs in Subareas 4-10 and 4-11 (Prince Rupert Harbour) and 1-6 (Masset Inlet). There also appears to be targeted fishing for humpback shrimp in Subareas 3-14 and 6-1 (Table 24). The subarea that experiences the most extensive humpback shrimp trap fishing is 4-10, in terms of weight of animals removed and effort. Although fishing effort in Subareas 6-1 and 4-11 was much lower than 4-10, it is still quite high compared to other subareas. More humpback shrimp were harvested from Subarea 3-14 than from 4-11 and 6-1, and with less fishing effort. Subarea 1-6 also experienced some directed humpback fishing pressure. CPUE was highest in Subarea 3-14 and lowest in 6-1.

4.0 DISCUSSION

4.1 ASSESSMENT AND MANAGEMENT OPTIONS

4.1.1 Fishing Mortality Rates

Gulland's (1971) proxy for an appropriate exploitation rate, based on the natural mortality rate, was applied to the data collected from this pilot study, suggesting that a 40% harvest rate would be appropriate for Drury Inlet humpback shrimp. However, this exploitation rate is probably biased high as it is based on a mortality rate determined over a four month fall/winter time frame which is a period of high senescence for female shrimp. In establishing a harvest rate for humpback shrimp, it would be appropriate and precautionary at this time to keep the target harvest rates in line with those presently used in the commercial shrimp trawl fishery (25% to 33%).

One of the pitfalls of applying a harvest rate model to a population as a whole is that the model assumes the commercial harvest is removing each age class in the same proportion that exists in the standing population. This is often not the case in shrimp fisheries where size selective targeting is taking place. Harvest rate decision rules must be adapted to provide age or size specific harvest rates to reflect fishery selectivity issues. Once a harvest rate has been determined for the shrimp stock, there must be a measureable target to which the harvest rate is applied against.

4.1.2 Fishery Independent Data (Using Pre-Season Shrimp Biomass Estimates)

Our first approach to provide a target to which the harvest rate can be applied against was to conduct a fishery independent biomass survey of the area. For shrimp stocks this is typically done using area-swept trawl surveys. Estimation of biomass for a species like humpback shrimp, however, is complicated because of the broad area and diversity of habitats these animals occupy. The results of the pilot study in Drury Inlet show only a fraction of the population exists on trawlable grounds; consequently, a single assessment technique such as an area-swept trawl survey is not adequate to provide an accurate biomass estimate. The use of relative indices of abundance from trap catches in trawlable and untrawlable areas is critical in providing a broader scale estimate of the population. One drawback of estimating shrimp biomass using spatial interpolation techniques is these methods produce a single biomass estimate with no variance around the estimate. Consequently, confidence intervals cannot be produced around the biomass estimate.

In an assessment framework for humpback shrimp, it would be advisable to develop other assessment techniques such as a depletion study or a mark-recovery experiment to test the adequacy of the assessment framework used in this pilot study. The depletion experiment that was attempted as part of this pilot project was not successful because the commercial vessels that volunteered to assist the DFO ceased fishing humpback shrimp after one day of effort, citing the small shrimp size to be commercially not viable.

Once the biomass of the humpback shrimp stock has been estimated, it is then possible to develop decision rules for the fishery. If, for example, the March 2002 humpback shrimp biomass estimate of 81.4 tons (Table 13) was used to develop catch quotas for potential commercial trawl and trap fisheries in Drury Inlet, one might calculate the quotas, depending on the harvest rate used, to be:

Catch Quota = $0.25 \times 81.4 = 20.4$ tons
Catch Quota = $0.33 \times 81.4 = 26.9$ tons
Catch Quota = $0.40 \times 81.4 = 32.6$ tons

Catch quotas for commercial trawl and/or trap fisheries in Drury Inlet based on March 2002 data would range from 20.4 to 32.6 tons, depending on the harvest rate used.

However, calculating quotas in this fashion does not take into account two factors: 1) ages 3+ shrimp will die after egg-hatch (which appears to start in March), and 2) the commercial fishery may only target the larger shrimp in the stock, for example ages 2+ shrimp. Catch quotas in this case should be established for this particular component of the stock, and not for all animals. The total weight of age 2 shrimp in Drury Inlet in March 2002 was estimated to be approximately 23.2 tons (Table 25). One might calculate the quotas, depending on the harvest rate used, to be:

Catch Quota = $0.25 \times 23.2 = 5.8$ tons
Catch Quota = $0.33 \times 23.2 = 7.7$ tons
Catch Quota = $0.40 \times 23.2 = 9.3$ tons

Catch quotas for commercial trawl and/or trap fisheries in Drury Inlet which would target age 2 shrimp would range from 5.8 tons to 9.3 tons, depending on the harvest rate used.

The complexity of how a fishery can impact on the shrimp stock and how it will affect the management decision rules highlights the need to monitor the fishery in-season to determine what component of the stock is being targeted. Collecting catch-at-age information throughout the fishery will have the added benefit of allowing for further modeling of the stock using standard catch-at-age models (this will require at least 10 years of data collection).

4.1.3 Fishery Dependent Data (Using CPUE as an Index of Relative Abundance)

As an alternative to developing a fishery independent biomass survey, we looked at the potential use of monitoring fishery dependent CPUE trends to measure population responses to a particular harvest rate. This was difficult to do in the pilot project as the depletion component of the study was not completed. What we did find, however, was that catch rates in repeated trawl catches were highly variable, even when trawling occurred at the same sites within the span of a few days. In addition, catch rates in trawl fisheries for highly mobile species such as shrimp are known to show a great deal of stationarity and are generally considered to be inadequate indicators of short term trends in biomass unless the trawling takes place over the entire range of the animal. Consequently, this management system would probably be inadequate for a trawl fishery.

In a trap fishery, gear can be fished over the entire habitat range of the shrimp; therefore, if sampling adequately covers the area, then the CPUE index should reflect population trends. This type of approach has been successful in the prawn trap fishery. Decision rules for a trap fishery using only fishery dependent CPUE indices might be obtained in the following manner. The mean CPUE estimate for MM trap catches in November 2001 in Drury Inlet was 47 female shrimp per trap (Table 6). One might calculate the quotas, depending on the harvest rate used, to be in November:

Catch Quota = 0.25×47 = 12 females per trap. CPUE should not fall below 35 females per trap.
Catch Quota = 0.33×47 = 16 females per trap. CPUE should not fall below 31 females per trap.
Catch Quota = 0.40×47 = 19 females per trap. CPUE should not fall below 28 females per trap.

Catch quotas derived from CPUE data for a commercial trap fishery in Drury Inlet beginning in November 2001 would range between 12 and 19 females per trap, depending on the harvest rate used. This would mean that CPUE estimates in November should not be allowed to fall below 28 and 35 females per trap, depending on the harvest rate used (Table 26 and Fig. 15). Decision rules for CPUE targets for future months can be determined by incorporating natural mortality estimates from the pilot study.

This type of management system will require an at-sea observer program which will measure the CPUE by age and sex of the shrimp at the beginning of the fishery to set the target shut-off points. Continual monitoring throughout the season is necessary to determine when the fishery should be closed. The critical difference between this monitoring system and the one presently used in the management of the prawn fishery is that the monitoring will have to begin immediately when the fishery opens because the decision rules must be established based on the results of the initial fishery. The other change is that not only will sex have to be determined, but a representative size frequency of the shrimp will also have to be collected. Standard logbook reporting of catch weight alone will not be sufficient for making management decisions.

4.1.4 Fixed Escapement Model – Egg Production Index

In the third management option, the decision rules for a trap fishery are based on leaving a fixed percentage of the maximum spawning potential. As discussed previously, the fixed percent rate would initially be chosen arbitrarily and will have to be tested over a wide range as the fishery develops. If, as an example, the fixed percentage was determined to be 30%, then the decision rules for a fishery might be determined in the following manner. The estimate of the total number of shrimp eggs produced in March in Drury Inlet was 1,688,600,547 eggs (Table 12). This means that 506,580,164 eggs should remain in the population to hatch in March. To produce the required number of eggs, 749,379 age 2 shrimp would have to survive to March (the assumption being all ages 3+ shrimp would be harvested by the fishery). The mean size of age 2 female shrimp in Drury Inlet in March, determined from trawl data, was 22.2 mm carapace length. The model predicts that a shrimp this size should produce approximately 742 eggs.

The following is an example of how to incorporate these decision rules into a fishery dependent trap CPUE monitoring system. Using the MM trap catches in March for egged females (Table 7), the decision rule for shutting down the fishery would be based on having the equivalent of 11 age 2 spawners or 8,162 eggs per trap in March to ensure that 30% of the eggs in the population are allowed to hatch. Monthly numbers of spawners and their egg equivalents per trap were back-calculated from March (Table 27, Fig. 16) using the annual mortality rate $A = 0.86$, based on the instantaneous rate $Z = M = 2.0$ (Table 17).

The implementation of a management and assessment decision system like this would require an assessment framework which incorporates an experimental design in the developmental phase of a fishery to test for the most appropriate percentage of maximum spawning potential. The initial values should span the range from 20% to 80% repeated over a number of areas and years. This type of system will work well for new fisheries with a virgin biomass from which estimates of maximum spawning potential can be indexed. For areas that have existing fisheries, this technique may not be appropriate and a system based on fishing mortality as discussed above should be used. These types of decision rules could be applied to both trap and trawl fisheries; however, they would require a fishery independent survey for the trawl fishery for the same reason as stated for fishing rate decision rules. As with the other systems, there will be a need for in-season monitoring of the fishery and information will have to be collected on both the sex and size of the animals. It would also be advisable to collect more information on size/fecundity relationships in different areas.

4.2 BYCATCH

Bycatch is an issue of what and how much is caught, and to what extent the animals are harmed. From the pilot study we found that the compositions of the bycatch collected by trawl and trap gear were very different. From a management perspective, the management of bycatch would have to incorporate decisions about what species and how many individuals are being caught, and what, if any, are the resulting mortalities on the bycatch species of concern.

In the pilot study, the animals captured by trawl gear appeared to be in poorer physical condition than those captured by trap gear. Bycatch released into the sea after being collected by trawl gear appeared to be dead and experienced heavy predation from seagulls and other birds. During research surveys in Drury Inlet, tow times were relatively short (20 minutes) compared to tow times that commercial fishers would normally do. Consequently, animals caught in commercial trawl gear will be subject in most instances to longer tow times and ultimately more crushing in the codend of nets. This fishing practice will lead to as much or more physical damage than what we witnessed from our surveys.

In contrast, bycatch released from trap gear appeared to be in good condition and seemed to avoid predation by birds. However, the pilot study could not confirm if there were any longterm effects that may have resulted in an increase in mortality due to handling.

Although bycatch may be reduced in shrimp fisheries through technological innovations or changes in exploitation methods, both trawl and long-lined trap gear are capable of causing collateral damage to habitats, especially sessile habitat forming organisms such as sponges and corals. Bottom trawling likely causes more extensive physical damage to benthic communities than trapping. Trawling can remove some physical features, cause a reduction in structural biota, a reduction in complexity, and alter the physical structure of the sea floor.

Impacts from trawl and trap gear will vary by area and species, but as the fisheries grow, fishing will occur in more areas that have not been previously exploited or surveyed. A priority should be made to understand the environmental impacts of trawl and trap gear. Commercial fisheries should develop using the fishing method that minimizes the most critical collateral damage. This may ultimately result in fishers having to change their fishing methodology. Bycatch is a serious issue in all fisheries and an observer program to monitor bycatch should be considered for directed humpback shrimp trawl and trap fisheries. These programs, however, could be part of any at-sea sampling that is required depending on the management and assessment option chosen.

4.3 COMMERCIAL HUMPBACK SHRIMP FISHING AREAS

The criteria outlined for identifying directed humpback shrimp fishing areas is acceptable for those fisheries that are presently taking place; however, it is not adequate for new and expanding fisheries. The collective knowledge of industry and DFO staff is required to identify humpback shrimp fishing areas other than those highlighted in this paper.

5.0 CONCLUSIONS AND RECOMMENDATIONS

1. If humpback shrimp fisheries are going to be managed by controlling fishing mortality rates, then the decision rules should be based on harvest rates of 25% to 33%.

2. Decision rules for controlling fishing mortality rates must be age and size specific to address variations in selectivity of different gear types.

3. Assessment of a humpback shrimp trawl fishery for input into the decision rules should be based on information from fishery independent biomass surveys.

4. Assessment of a humpback shrimp trap fishery for input into the decision rules can be based on information from either fishery independent or fishery dependent indices of abundance.

5. Fishery independent biomass surveys for humpback shrimp should be conducted using a combination of trawl and trap sampling techniques.

6. If a humpback shrimp fishery is going to be managed through control rules based on a fixed percentage of maximum spawning potential, it would be precautionary to start at a 70% level and then develop a systematic testing protocol to measure the response at much lower levels. At this time the fixed percentage should not fall below 30%.

7. Control rules based on a fixed percentage of maximum spawning potential should only be considered in areas that do not have a history of extensive fishing.

8. Decision rules based on at-sea assessments of fishery dependent indices must be collected at the start of each fishing year to establish the fishery decision rules for that year.

9. Fishery dependent indices from traps will have to include information on the size and sex of humpback shrimp, not on weight alone.

10. To help in the assessment of fishery dependent indices, the industry should be developed using a standard trap, although mesh size may vary by area depending on humpback shrimp growth rates.

11. Bycatch issues will vary by area and gear-type. At-sea observer coverage will be required to assess bycatch issues.

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TABLES

Table 1. Comparisons of humpback shrimp sex stages CPUE by traps with different mesh sizes in Drury Inlet, November 2001. Traps are listed in order from largest (LM model) to smallest (SM model) mesh size.

Habitat	Trap Type	Immature Male		Male		Transitional		Female Non-egged		Female Egged		Female Spent		Mean Number Per Trap
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Trawlable -	LM	0	0	0	1	0	1	9	98	0	0	0	0	9
Main Inlet	MM	0	0	2	3	1	1	74	97	0	0	0	0	76
	SM	0	0	12	10	1	1	106	89	0	0	0	0	119
Rocky -	LM	0	0	0	22	0	0	1	78	0	0	0	0	2
Main Inlet	MM	0	0	0	1	0	0	30	99	0	0	0	0	31
	SM	0	0	4	10	1	1	39	88	0	0	0	0	44
Reaches	LM	0	0	0	0	0	6	1	94	0	0	0	0	2
Upper	MM	0	0	1	3	0	2	25	95	0	0	0	0	26
	SM	0	0	5	15	1	3	29	82	0	0	0	0	35
All Inlet	LM	0	0	0	4	0	2	5	95	0	0	0	0	5
	MM	0	0	1	2	0	1	47	97	0	0	0	0	49
	SM	0	0	8	11	1	1	65	88	0	0	0	0	73

Table 2. Comparisons of humpback shrimp sex stages CPUE by traps with different mesh sizes in Drury Inlet, March 2002. Traps are listed in order from largest (LM model) to smallest (SM model) mesh size.

Habitat	Trap Type	Immature Male		Male		Transitional		Female: Non-egged		Female: Egged		Female: Spent		Mean Number Per Trap
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Trawlable -	LM	0	0	0	2	0	4	1	18	4	72	0	4	5
Main Inlet	MM	0	0	3	5	4	7	11	18	38	64	4	6	60
	SM	0	0	31	27	20	17	18	15	43	37	5	4	115
Rocky -	LM	0	0	0	1	0	1	0	3	2	91	0	4	2
Main Inlet	MM	0	0	1	3	2	9	4	14	19	70	1	4	27
	SM	0	0	24	34	18	26	8	11	25	35	2	3	73
Reaches	LM	0	0	0	0	0	0	0	7	3	87	0	7	3
Upper	MM	0	0	5	9	6	10	3	6	42	71	3	5	60
	SM	0	0	22	27	16	20	1	1	39	48	3	4	82
All Inlet	LM	0	0	0	1	0	3	1	14	3	77	0	5	4
	MM	0	0	3	6	4	8	7	14	32	67	3	5	47
	SM	0	0	27	29	19	20	11	12	35	38	3	4	93

Table 3. Trap gear CPUE estimates by humpback shrimp age in Drury Inlet, November 2001. Mean ± SD.

Age	Carapace Length (mm)	Trap Type	
		MM	SM
0	<9.5	0 ± 0	0 ± 0
1	9.5-19.8	1 ± 2	9 ± 8
2	19.9-23.1	16 ± 13	31 ± 25
3	23.2 +	33 ± 23	36 ± 25

Table 4. Trap gear CPUE estimates by humpback shrimp age in Drury Inlet, March 2002. Mean ± SD.

Age	Carapace Length (mm)	Trap Type	
		MM	SM
0	<13.9	0 ± 0	0 ± 0
1	13.9-20.4	5 ± 7	44 ± 30
2	20.5-23.5	25 ± 27	33 ± 25
3	23.6 +	17 ± 13	18 ± 16

Table 5. Trap gear CPUE estimate changes for humpback shrimp by age class in Drury Inlet in March 2002 compared to November 2001. This table summarizes Tables 3 and 4.

Age	Trap Type	
	MM	SM
0	= [1]	=
1	++ [2]	++
2	+ [3]	=
3	-- [4]	--

[1] = CPUE similar (within 5 shrimp per trap)
[2] ++ CPUE increase, approximately more than double
[3] + CPUE increase
[4] -- CPUE decrease, approximately half

Table 6. Trap gear CPUE estimates for humpback shrimp by sexual condition in Drury Inlet, November 2001. Mean ± SD.

Habitat	Reproductive Status	Trap Type MM	Trap Type SM
Trawlable – Main Inlet	Non-egg[1]	3 ± 3	13 ± 10
	Egg[2]	74 ± 39	106 ± 46
	Total No[3]	76 ± 39	119 ± 47
Rocky – Main Inlet	Non-egg	0 ± 1	5 ± 5
	Egg	30 ± 33	39 ± 40
	Total No	31 ± 34	44 ± 41
Upper Inlet	Non-egg	1 ± 2	6 ± 4
	Egg	25 ± 27	29 ± 36
	Total No	26 ± 28	35 ± 38
All Inlet	Non-egg	1 ± 2	9 ± 8
	Egg	47 ± 42	65 ± 55
	Total No	49 ± 43	73 ± 59

[1]Non-egg = immature, male, and transitional
[2]Egg = female: not gravid, gravid and spent
[3]Total No = all humpback shrimp sex stages

Table 7. Trap gear CPUE estimates for humpback shrimp by sexual condition in Drury Inlet, March 2002. Mean ± SD.

Habitat	Reproductive Status	Trap Type MM	Trap Type SM
Trawlable – Main Inlet	Non-egg[1]	18 ± 17	68 ± 36
	Egg[2]	42 ± 35	47 ± 32
	Total No[3]	60 ± 48	115 ± 62
Rocky – Main Inlet	Non-egg	7 ± 9	51 ± 48
	Egg	20 ± 24	27 ± 26
	Total No	27 ± 29	78 ± 70
Upper Inlet	Non-egg	15 ± 15	39 ± 32
	Egg	45 ± 49	42 ± 42
	Total No	60 ± 52	82 ± 59
All Inlet	Non-egg	13 ± 15	56 ± 42
	Egg	34 ± 36	39 ± 33
	Total No	47 ± 45	95 ± 67

[1]Non-egg = immature, male, transitional, and females not gravid or spent
[2] Egg = females: gravid and spent
[3] Total No = all humpback shrimp sex stages

Table 8. Trap gear CPUE estimate changes for humpback shrimp by sexual condition in Drury Inlet in March 2002 compared to November 2001. This table is a summary of Tables 6 and 7.

Habitat	Reproductive Status	Trap Type MM	Trap Type SM
Trawlable – Main Inlet	Non-egg	++ [1]	++
	Egg	- [3]	-- [4]
	Total No	-	=
Rocky – Main Inlet	Non-egg	++	++
	Egg	-	-
	Total No	= [5]	+
Upper Inlet	Non-egg	++	++
	Egg	+ [2]	+
	Total No	++	++
All Inlet	Non-egg	++	++
	Egg	-	-
	Total No	=	+

[1] ++ CPUE increase, more than double
[2] + CPUE increase
[3] - CPUE decrease
[4] -- CPUE decrease, more than half
[5] = CPUE similar (within 5 shrimp per trap)

Table 9. Trap gear CPUE estimates for humpback shrimp by weight in Drury Inlet, November 2001 and March 2002.

Date	Trap Type	Humpback Wt (kg)	Effort (# traps)	CPUE (kg per trap)
Nov 2001	MM	54	116	0.47
Nov 2001	SM	76	116	0.65
Mar 2002	MM	51	116	0.44
Mar 2002	SM	79	117	0.68

Table 10. Age structure of humpback shrimp in Drury Inlet, 2001 and 2002. Shrimp were collected with trawl gear.

Date	Age Structure			Carapace Length (mm)		von Bertalanffy Parameters		
	Year	Carapace Size (mm)	Proportion-at-age	Min	Max	L_∞	K	T_0
Nov 2001	0	0-9.4	0.001	9.4	28.3	26.01	0.75	0.39
	1	9.5-19.8	0.58					
	2	19.9-23.1	0.34					
	3	23.2+	0.08					
Mar 2002	0	0-13.8	0.003	10.2	28.4	26.71	0.68	0.22
	1	13.9-20.4	0.66					
	2	20.5-23.5	0.31					
	3	23.6+	0.03					

Table 11. Humpback shrimp mean carapace lengths (mm) by age in Drury Inlet, November 2001 and March 2002.

Date	Humpback Shrimp Age			
	0	1	2	3+
Nov 2001	9.4	18.1	21.7	24.7
Mar 2002	10.9	18.6	22.0	24.8
Growth Per Month	0.38	0.11	0.10	0.03

Table 12. Humpback shrimp egg production in Drury Inlet, March 2002.

Age	Mean No. Eggs per Shrimp	n	% Shrimp Gravid or Spent[1]	No. Shrimp	No. Shrimp Gravid or Spent	Total No. Eggs Produced
1	545	3	1.3	9,679,900	128,743	70,164,935
2	676	13	60.6	3,408,500	2,066,574	1,397,004,024
3	1,141	14	89.7	216,400	194,068	221,431,588
						1,688,600,547

[1] Based on trawl data

Table 13. Humpback shrimp biomass in Drury Inlet, November 2001 and March 2002.

Date	Humpback Shrimp Biomass (tons)			
	Trawlable Area ($12.8\ km^2$)	Untrawlable Area ($27.2\ km^2$)	Total Biomass	$Tons/km^2$
Nov 2001	24.3	19.5	43.8	1.9
Mar 2002	28.9	52.5	81.4	2.3

Table 14. Comparison of the number of humpback shrimp collected per trap (SM model) in different habitat types in Drury Inlet, November 2001 and March 2002.

Location	Date	Mean Number Shrimp per Trap	Mean Soak Time (Hrs: Min)	Mean Depth (m)
Trawlable - Main Inlet	Nov 2001	119	18:26	50
	Mar 2002	115	18:51	49
Rocky - Main Inlet	Nov 2001	44	21:33	45
	Mar 2002	86	19:55	47
Upper Inlet	Nov 2001	35	23:33	30
	Mar 2002	82	22:36	31
All Inlet	Nov 2001	76	20:30	45
	Mar 2002	95	20:02	45

Table 15. Humpback shrimp densities by age (number of shrimp in thousands) in Drury Inlet, November 2001 and March 2002.

Date	Age 1		Age 2		Ages 3+	
	No.	%	No.	%	No.	%
Nov 2001	4001.9	0.61	1880.2	0.29	675.6	0.10
Mar 2002	9679.9	0.73	3408.5	0.26	216.4	0.02

Table 16. Weight (in kg) of humpback shrimp collected in replicate tows in Drury Inlet, November 2001 and March 2002. Tow locations in November and March were identical.

	Nov 2001				Mar 2002			
Site #	Initial Tow	Replicate Tow	Mean	Variance	Initial Tow	Replicate Tow	Mean	Variance
1	34	28	31	22	25	20	23	15
2	49	48	48	0	35	22	28	78
3	34	28	31	19	23	14	18	34
4	51	13	32	722	31	28	30	5
5	30	25	27	10	21	54	38	541
6	84	6	45	2995	17	14	15	6

Table 17. Estimates of natural mortality (M), total mortality (A) and survival rates (S) for humpback shrimp in Drury Inlet.

Type	Fishing Gear	n1 [a]	n2 [a]	Months	M	A [b]	S [c]
By age	Trap MM	33	17	4	1.99	0.86	0.14
By age	Trap SM	36	18	4	2.08	0.88	0.12
By sex	Trap MM	47	34	4	0.97	0.62	0.38
By sex	Trap SM	65	39	4	1.53	0.78	0.22
By pop. size	Trawl / Trap	675.6	216.4	4	3.42	0.97	0.03
Average					2.00	0.86	0.14

[a] n1, n2 are trap CPUE or age 3 shrimp density estimates determined at two points in time.
[b] A is the actual total mortality rate. $A = 1 - e^{-Z}$ where Z = M.
[c] S is the survival rate. $S = e^{-Z}$ where Z = M.

Table 18. Bycatch species collected with trawl gear in Drury Inlet, November 2001 and March 2002. These species represented less than 1% of the total catches. Species are listed in alphabetical order by common name.

Common Name	Scientific Name
Arrowtooth flounder	*Atheresthes stomias*
Bivalve mollusc	*Bivalvia* spp.
Coonstripe shrimp	*Pandalus danae*
Eualid	*Eualus* spp.
Eulachon	*Thaleichthys pacificus*
Flathead sole	*Hippoglossoides elassodon*
Goby	*Gobiidae* spp.
Gunnel	*Pholidae* spp.
Hermit crab	*Paguridae* spp.
Northern sculpin	*Icelinus borealis*
Pacific staghorn sculpin	*Leptocottus armatus*
Pink shrimp (flexed)	*Pandalus goniurus*
Poacher	*Agonidae* spp.
Polychaete worm	*Polychaeta* spp.
Prawn	*Pandalus platyceros*
Prickleback	*Stichaeidae* spp.
Rex sole	*Errex zachirus*
Sand sole	*Psettichthys melanostictus*
Sculpin	*Cottidae* spp.
Sidestripe shrimp	*Pandalopsis dispar*
Slender sole	*Eopsetta exilis*
Snailfish	*Liparinae* spp.
Spiny side shrimp (spiny lebbeid)	*Lebbeus groenlandicus*
Squid	*Teuthoidea* spp.
Walleye pollock	*Theragra chalcogramma*
Whitebait smelt	*Allosmerus elongatus*
Yellowtail rockfish	*Sebastes flavidus*

Table 19. Bycatch species collected with trap gear in trawlable habitat in Drury Inlet, November 2001 and March 2002. These species represented less than 1% of the total catches. Species are listed in alphabetical order by common name.

Common Name	Scientific Name
Argids	*Argis* spp.
Coonstripe shrimp	*Pandalus danae*
Crangon	*Crangon* spp.
Decorator crab	*Oregonia gracilis*
Dungeness crab	*Cancer magister*
Eelpout	*Zoarcidae* spp.
English sole	*Pleuronectes vetulus*
Eualid	*Eualus* spp.
Fish-eating star	*Stylasterias forreri*
Giant wrymouth	*Cryptacanthodes gigantea*
Marbled snailfish	*Liparis dennyi*
Pacific staghorn sculpin	*Leptocottus armatus*
Pink shrimp	*Pandalus borealis*
Pink shrimp (flexed)	*Pandalus goniurus*
Prawn	*Pandalus platyceros*
Quillback rockfish	*Sebastes maliger*
Sand sole	*Psettichthys melanostictus*
Shiner perch	*Cymatogaster aggregata*
Snailfish	*Liparinae* spp.
Spiny side shrimp (spiny lebbeid)	*Lebbeus groenlandicus*
Yellowtail rockfish	*Sebastes flavidus*

Table 20. Number of species collected using traps with different mesh sizes. November 2001 and March 2002 data listed in that order. Traps are listed in order from smallest to largest mesh size.

	Number of Species Collected (Nov / Mar)				
Trap Type	Fish	Crab	Starfish	Shrimp	Total
SM	8 / 5	5 / 4	1 / 1	9 / 8	23 / 18
MM	8 / 7	4 / 4	2 / 1	7 / 7	21 / 19
LM	7 / 6	4 / 5	1 / 1	5 / 5	17 / 17

Table 21. Fish species collected by trap gear (SM, MM, LM models).

Common Name	Scientific Name
Shiner perch	*Cymatogaster aggregata*
Copper rockfish	*Sebastes caurinus*
Quillback rockfish	*Sebastes maliger*
Yellowtail rockfish	*Sebastes flavidus*
Sand sole	*Psettichthys melanostictus*
English sole	*Pleuronectes vetulus*
Pacific staghorn sculpin	*Leptocottus armatus*
Great sculpin	*Myoxocephalus polyacanthocephalus*
Buffalo sculpin	*Enophrys bison*
Giant wrymouth	*Cryptacanthodes gigantea*
Eelpouts	*Zoarcidae* spp.
Marbled snailfish	*Liparis dennyi*

Table 22. Number of species collected by trawl and trap fishing gear in trawlable areas in Drury Inlet, November 2001 and March 2002.

	Number of Species Collected							
Fishing Gear	Fish	Crab	Shrimp	Starfish	Mollusc	Worm	Squid	Total
Trawl	23	1	10	0	1	1	1	37
Trap	13	4	9	2	0	0	0	28

Table 23. Subareas where humpback shrimp were targeted by commercial trawl gear, June 2001 to May 2002. The weights listed are not total landings but catches where humpback shrimp were equal to or greater than other shrimp species.

Subarea	Humpback Wt Total Landings (kg)	Humpback Wt Targeted Fishery (kg)	Effort (min. towed)	CPUE (kg/min towed)
4-9	8,070	6,107	15,959	0.38
5-4	3,333	3,197	3,585	0.89
12-39	4,395	3,121	13,190	0.24
4-12	4,339	2,666	5,230	0.51
3-4	2,032	2,032	3,930	0.52
5-5	1,880	1,653	1,600	1.03
6-23	1,946	1,492	470	3.17
13-24	1,445	1,445	5,625	0.26

Table 24. Subareas where humpback shrimp were targeted by commercial trap gear, May 2001 to April 2002.

Subarea	Humpback Wt (kg)	Effort (# traps)	CPUE (kg per trap)
4-10	11,862	77,957	0.15
3-14	3,567	6,450	0.55
4-11	2,771	13,825	0.20
6-1	1,939	16,180	0.12
1-6	907	4,425	0.20

Table 25. Estimated total weights of humpback shrimp in the various age classes in Drury Inlet in March 2002.

Age	No. of Shrimp	Mean Individual Wt. (g)	Age Class Wt. (tons)
1	9,679,900	4.638	44.9
2	3,408,500	6.809	23.2
3	216,400	9.361	2.0

Table 26. Catch quotas for a humpback shrimp trap fishery in Drury Inlet based on fishery dependent CPUE data of female shrimp. Please refer to Figure 15 for a graphical display.

	CPUE (No. Females Per Trap)			
Month	No Fishing [a]	Fishing 25% [b]	Fishing 33% [c]	Fishing 40% [d]
Nov	47	35	31	28
Dec	40	30	27	24
Jan	34	25	23	20
Feb	28	21	19	17
Mar	24	18	16	14

[a] natural mortality only.
[b] 25% harvest rate and natural mortality.
[c] 33% harvest rate and natural mortality.
[d] 40% harvest rate and natural mortality.

Table 27. Mean monthly spawner index and egg equivalents for humpback shrimp based on Drury Inlet data. Please refer to Figure 16 for a graphical display.

Month	CPUE (No. Females Age 2 Per Trap)	CPUE (No. Eggs Per Trap)
April	65	48,230
May	55	40,810
June	47	34,874
July	40	29,680
Aug	34	25,228
Sept	29	21,518
Oct	24	17,808
Nov	21	15,582
Dec	17	12,614
Jan	15	11,130
Feb	13	9,646
Mar	11	8,162

FIGURES

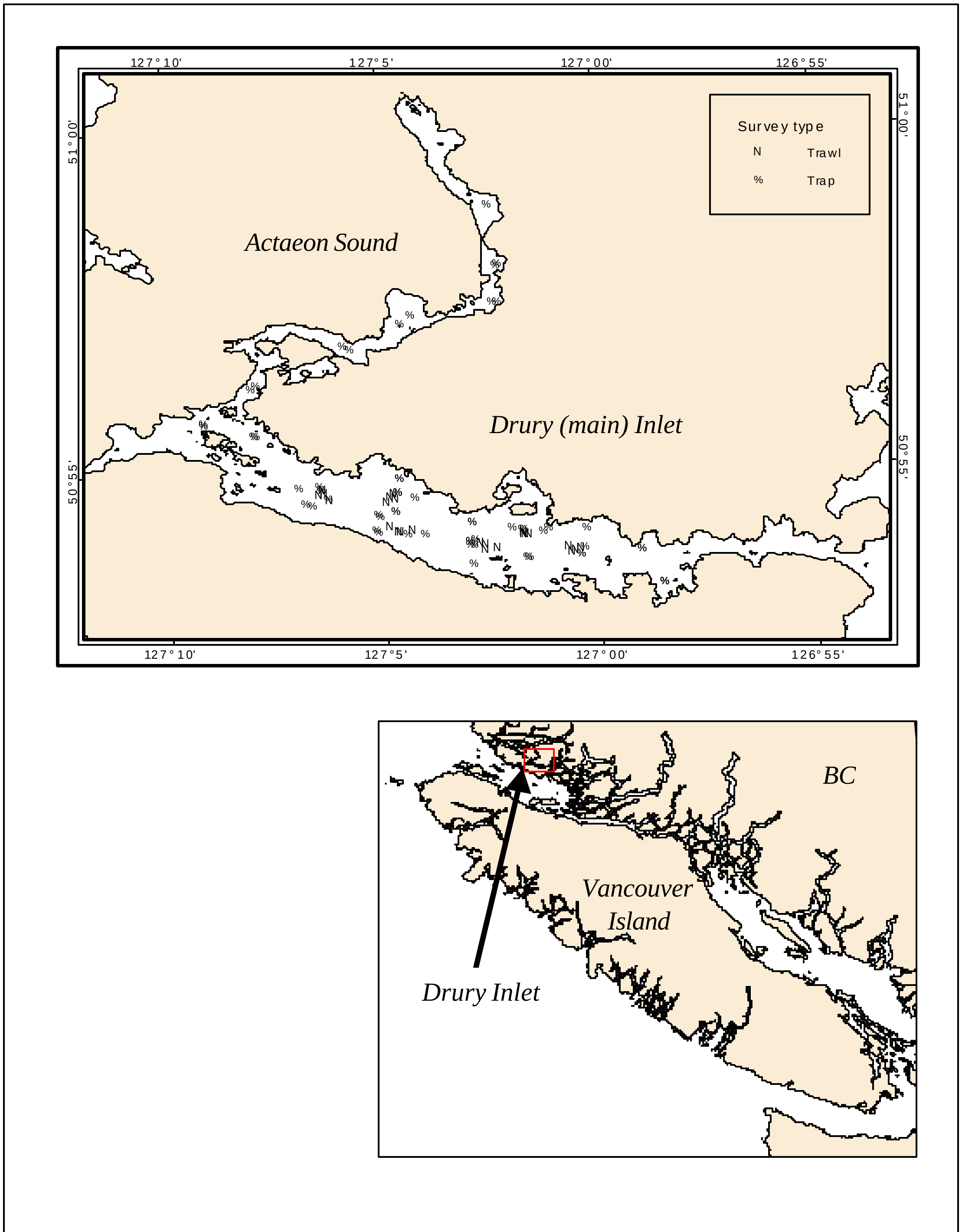


Figure 1. Map of Drury Inlet and trawl and trap gear sampling locations, November 2001 and March 2002.

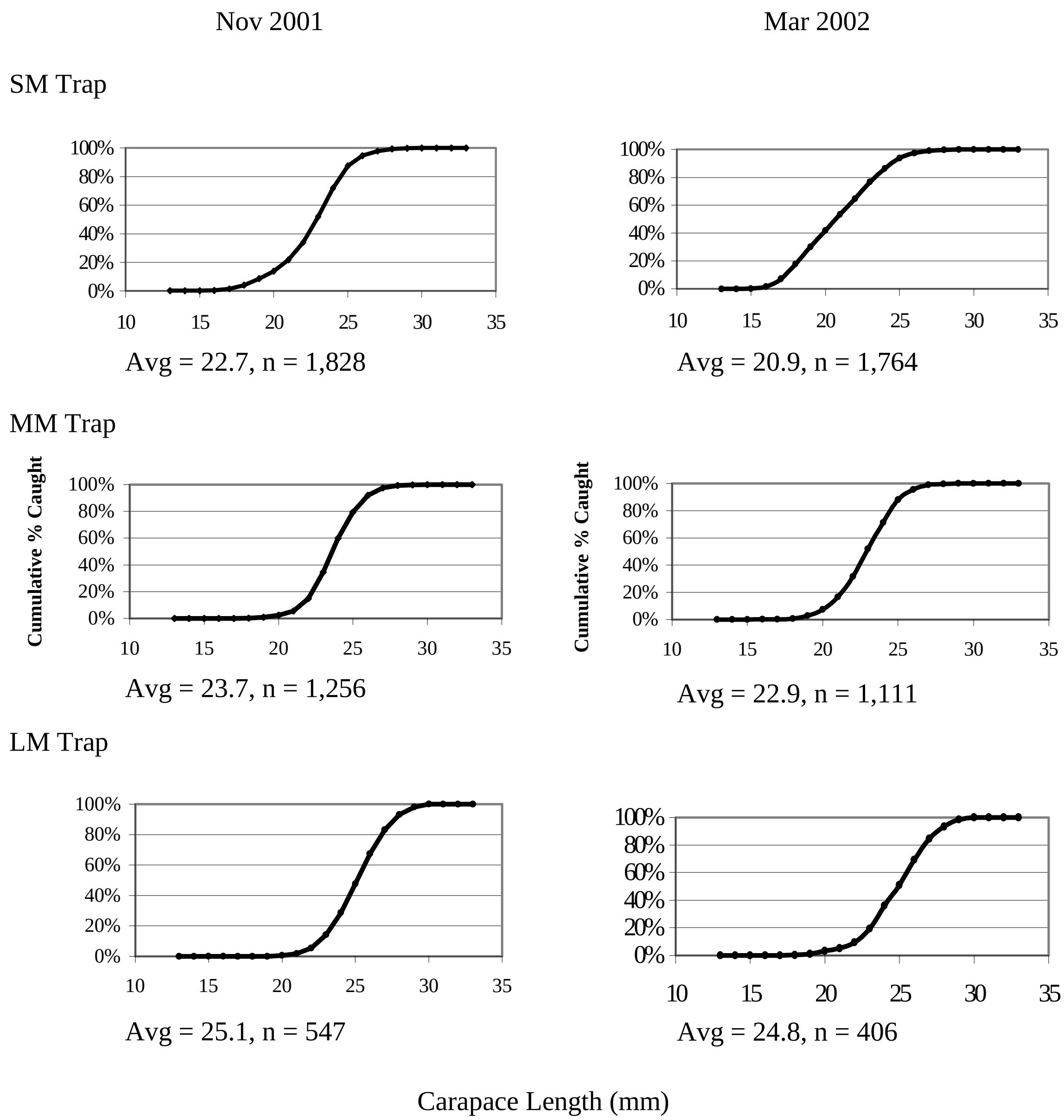


Figure 2. Size composition retention curves for humpback shrimp catches by trap type in Drury Inlet, November 2001 and March 2002. Mean carapace lengths and number of shrimp are provided. Trap types are arranged from smallest (SM) to largest mesh size (LM).

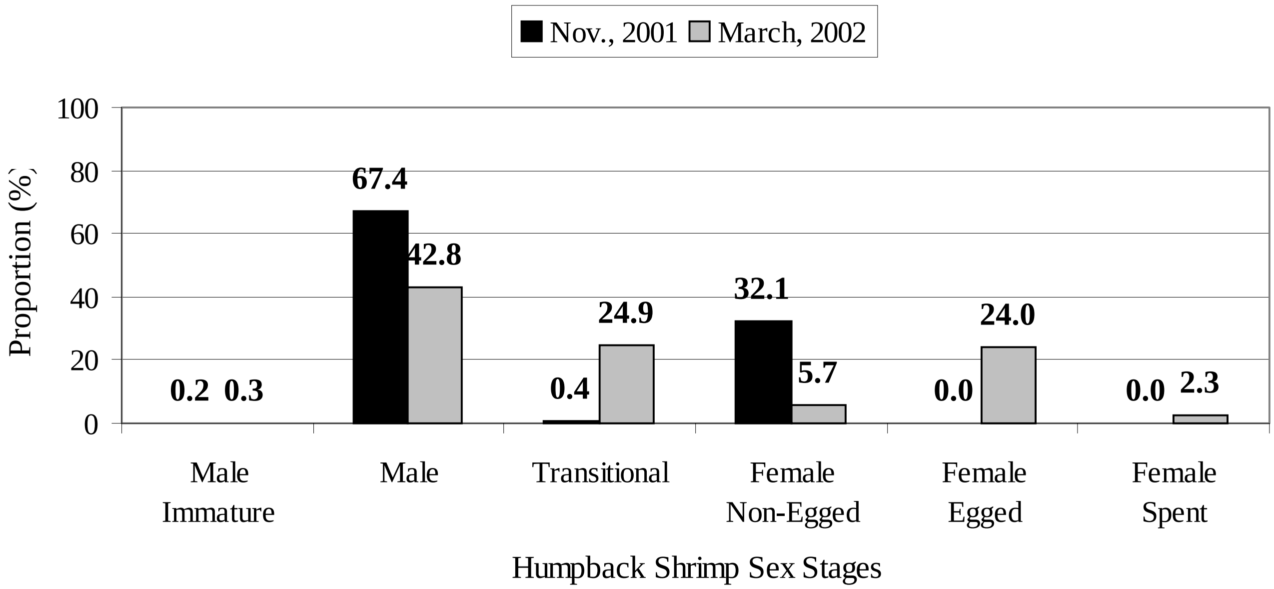


Figure 3. Proportions of humpback shrimp sex stages collected by trawl gear in Drury Inlet, November 2001 and March 2002.

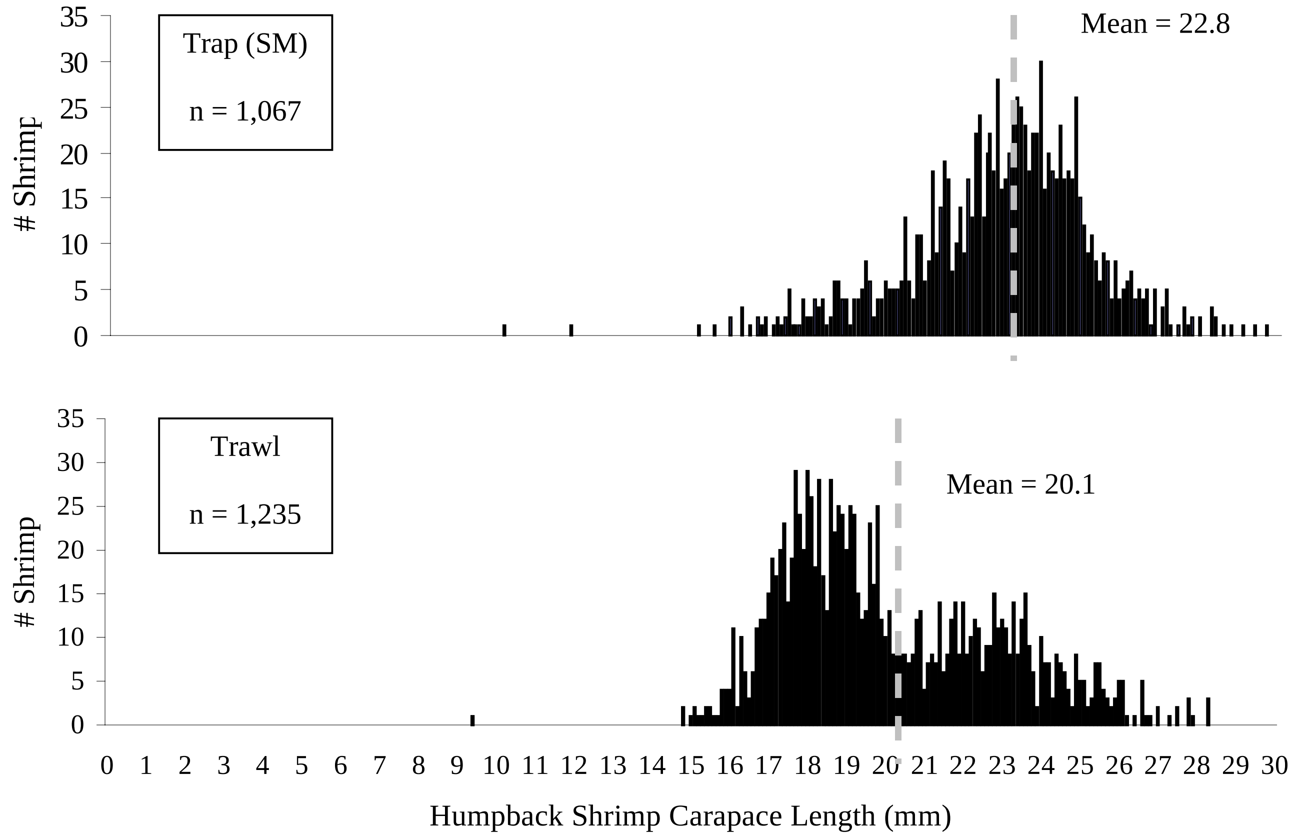


Figure 4. Length (carapace) of humpback shrimp collected with trap (SM model) and trawl gear in trawlable habitat in Drury Inlet, November 2001.

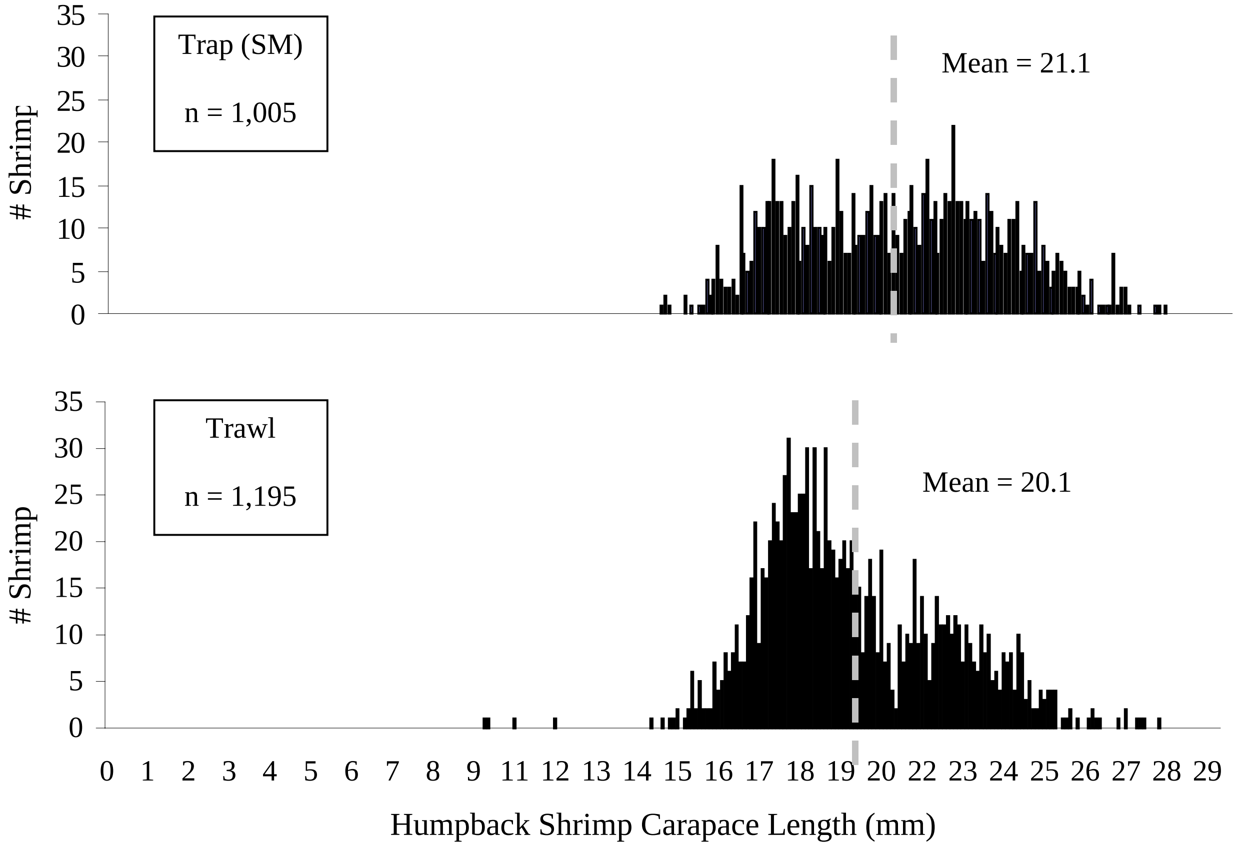


Figure 5. Length (carapace) of humpback shrimp collected with trap (SM model) and trawl gear in trawlable habitat in Drury Inlet, March 2002.

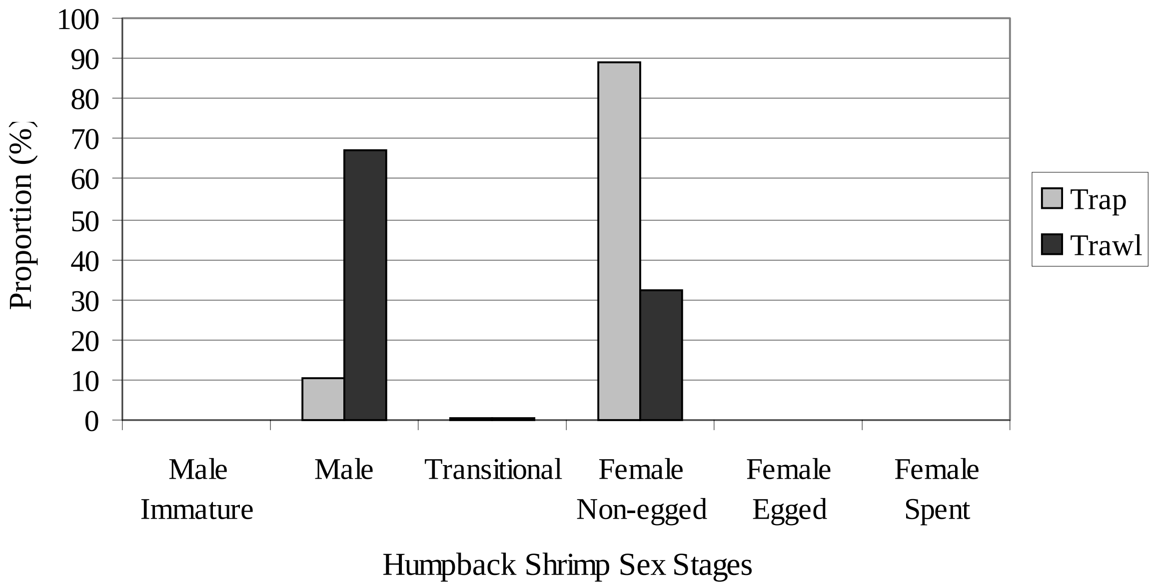


Figure 6. Proportions of humpback shrimp sex stages collected with trap and trawl gear in trawlable habitat in Drury Inlet, November 2001.

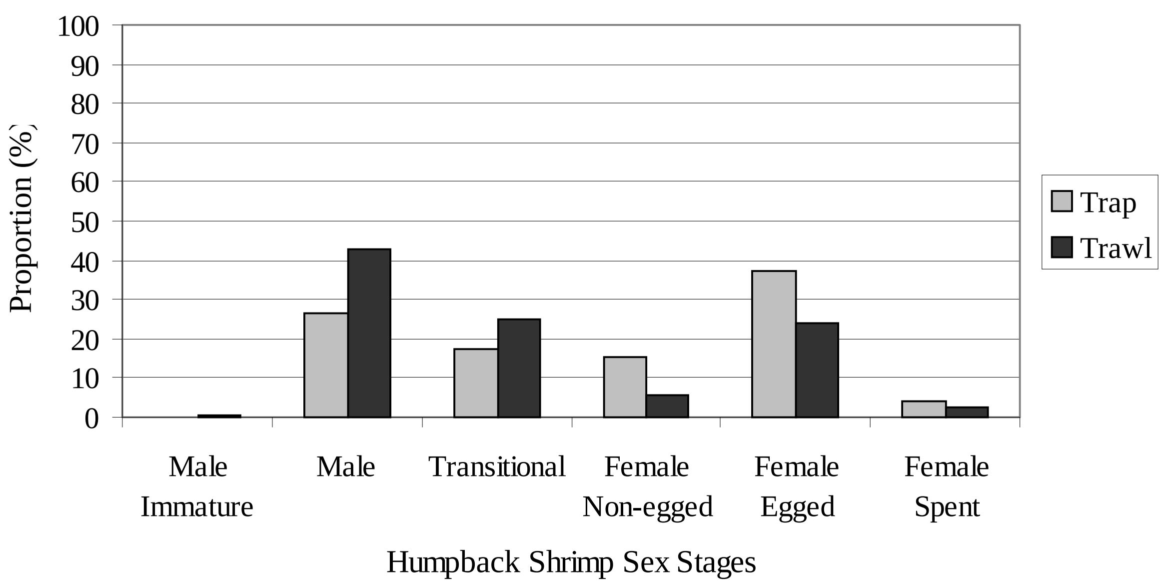


Figure 7. Proportions of humpback shrimp sex stages collected with trap and trawl gear in trawlable habitat in Drury Inlet, March 2002.

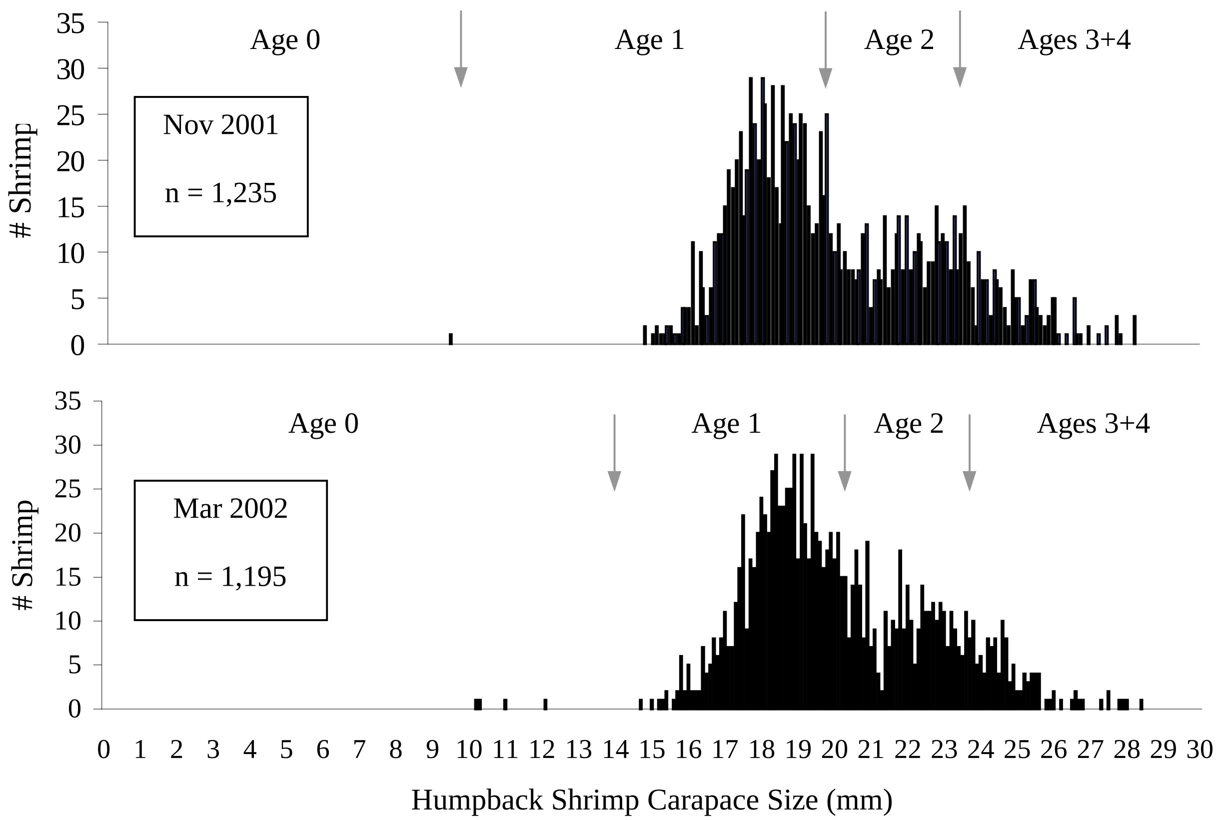
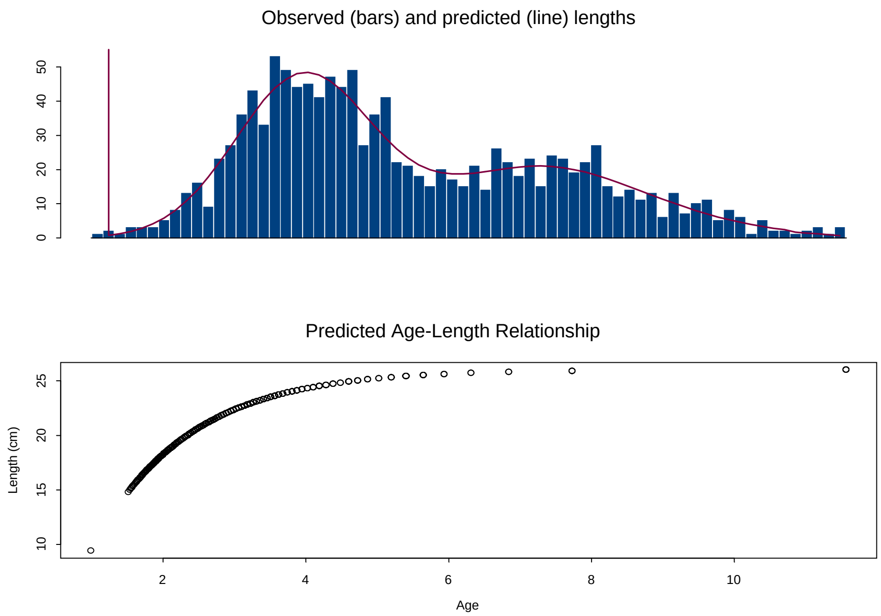


Figure 8: Humpback shrimp carapace lengths in Drury Inlet, November 2001 and March 2002. Shrimp were collected with trawl gear. Ages, as determined from length-frequency analysis, are shown.

A) November 2001



B) March 2002

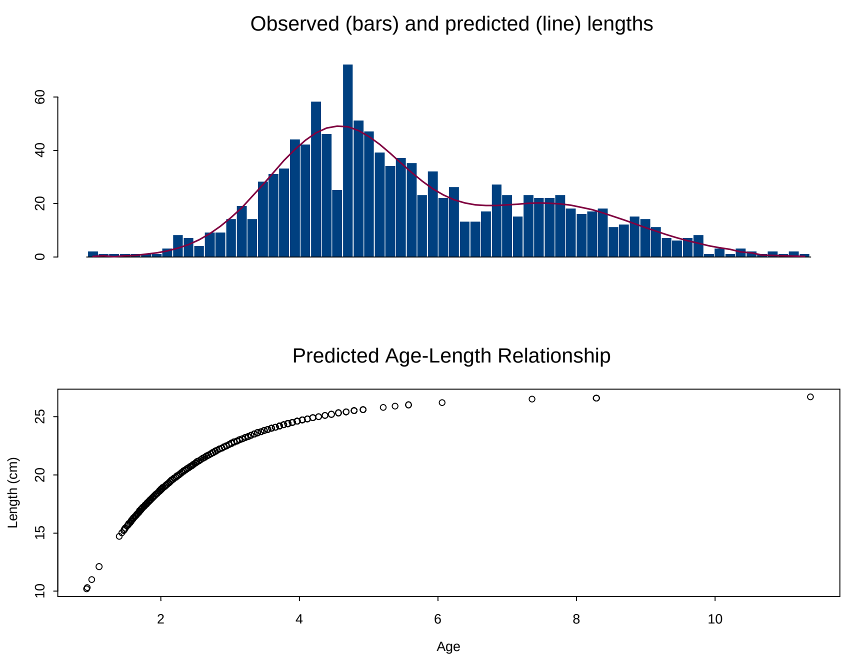


Figure 9. Von Bertelanffy growth curves for humpback shrimp in Drury Inlet, November 2001 and March 2002

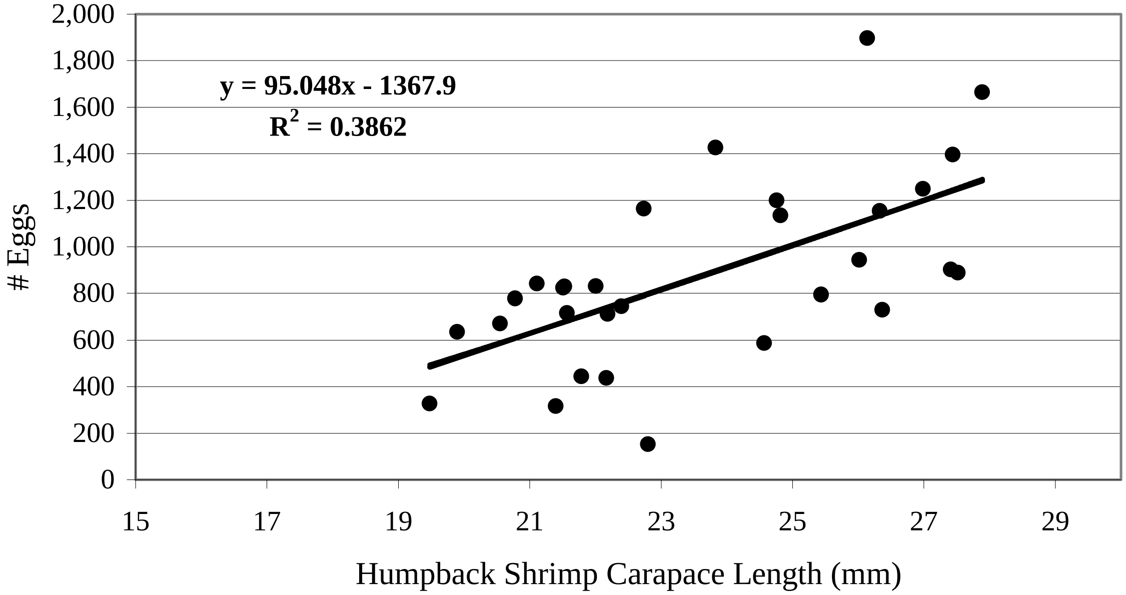


Figure 10. Relationship between female humpback shrimp size and fecundity in Drury Inlet, March 2002.

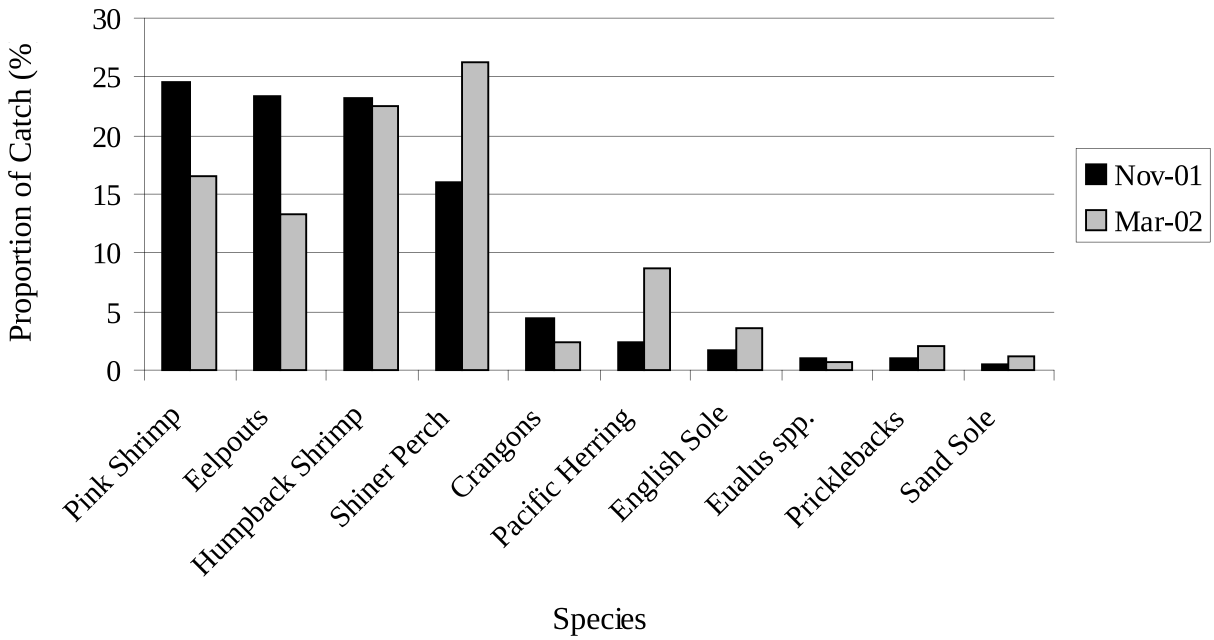


Figure 11. Trawl catch composition in Drury Inlet, November 2001 and March 2002. Species listed here represented more than 1% of the total catches.

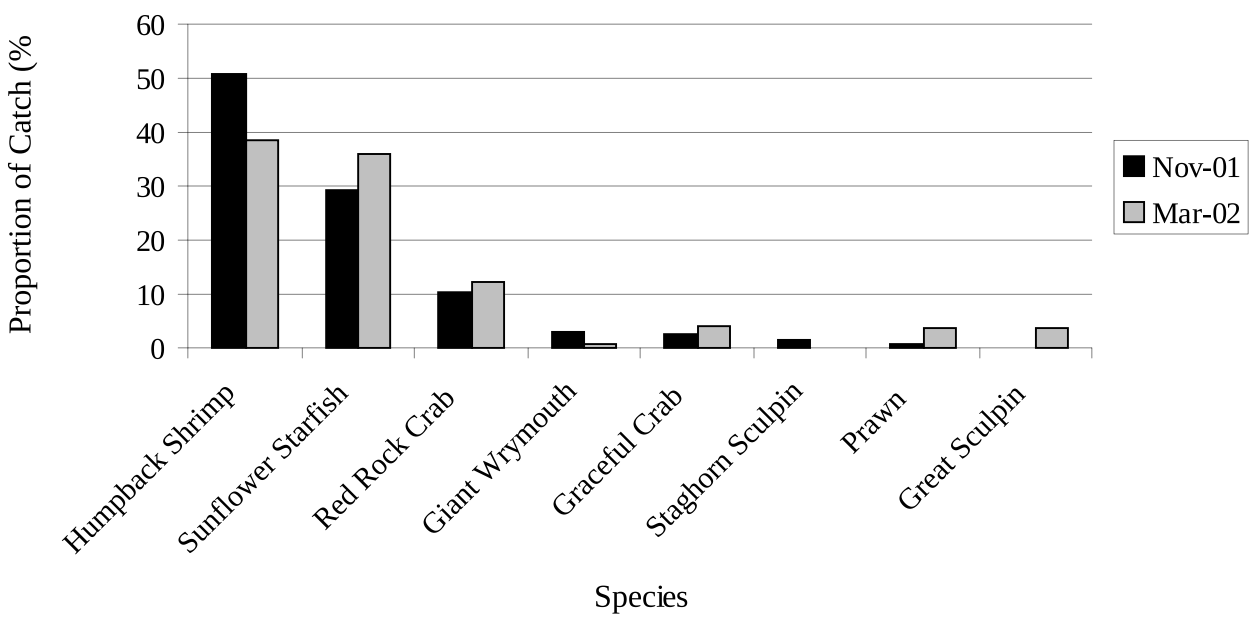


Figure 12. Trap catch composition in trawlable habitat in Drury Inlet, November 2001 and March 2002. Species listed here represented more than 1% of the total catches.

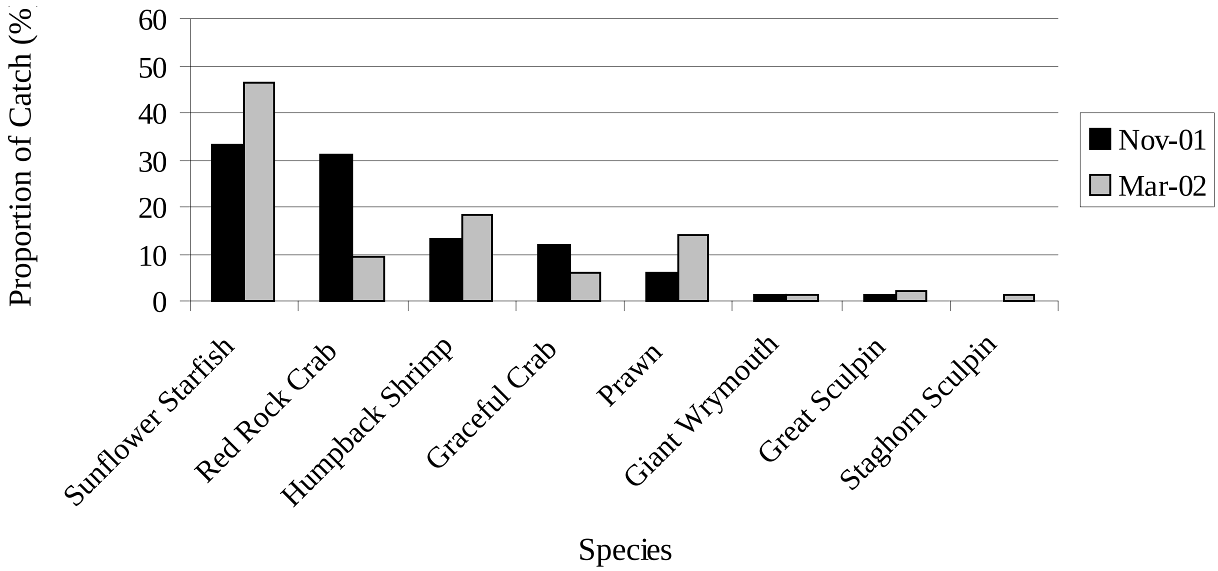


Figure 13. Trap catch composition in rocky habitat in Drury Inlet, November 2001 and March 2002. Species listed here represented more than 1% of the total catches.

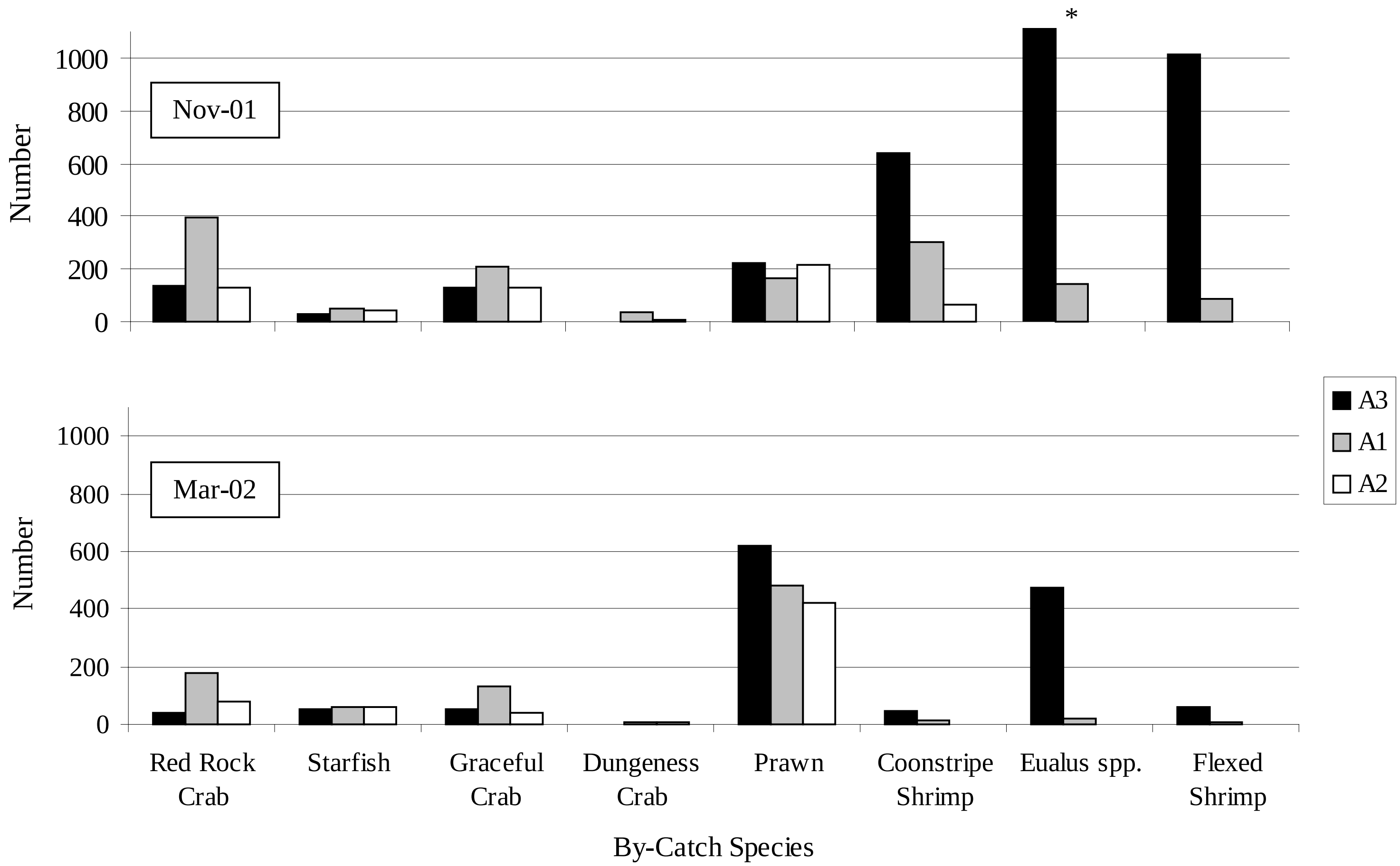


Figure 14. Bycatch species collected using three trap models (SM, MM, LM) in Drury Inlet, November 2001 and March 2002. Traps are listed in order of mesh size – small to large.

[*] 1,757 eualids were collected and this is not reflected on the graph

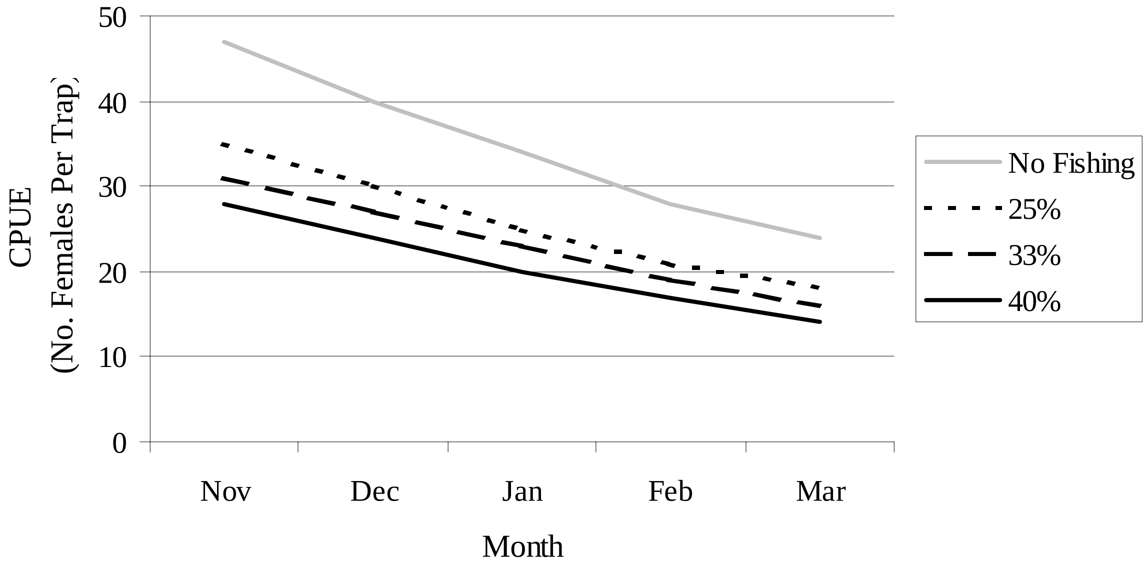


Figure 15. Catch quotas for a humpback shrimp trap fishery in Drury Inlet based on fishery dependent CPUE data of female shrimp. Please refer to Table 26 for monthly values. Trap CPUE estimates of the number of female shrimp were collected in November. “No Fishing” refers to the decline in numbers of females per trap that would occur due to natural mortality only. Target CPUE estimates are derived from 25%, 33%, and 40% harvest rates applied to survivors each month.

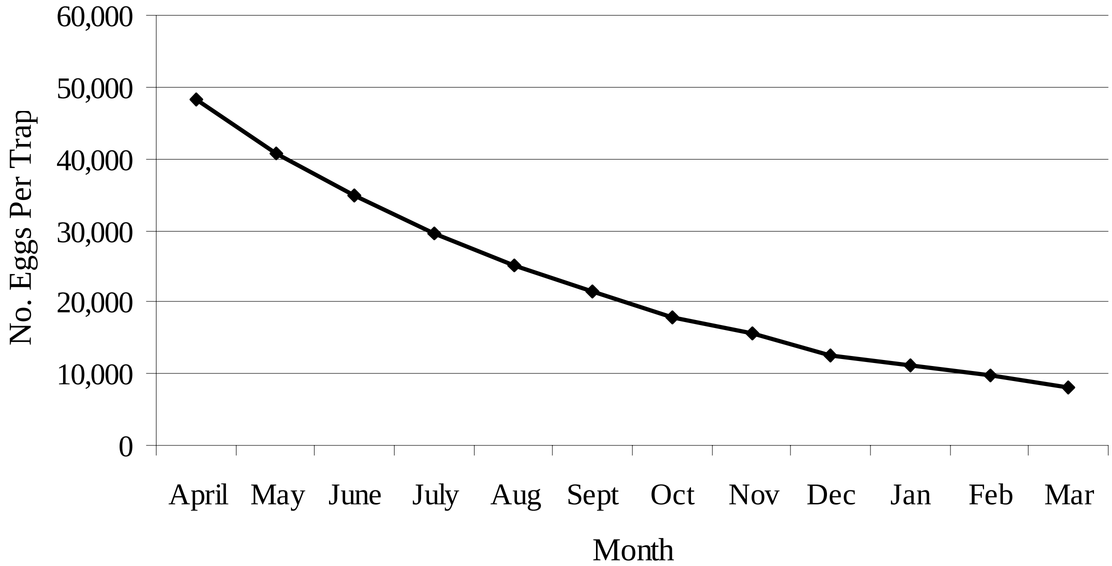


Figure 16. Mean monthly egg production index for humpback shrimp based on Drury Inlet data. Please refer to Table 27 for monthly values. The index was developed based on the requirement that 30% of the total number of eggs produced are allowed to hatch in March. Values for months other than March were back-calculated using the Drury Inlet humpback shrimp annual mortality rate.

APPENDIX 1

PSARC INVERTEBRATE SUBCOMMITTEE REQUEST FOR WORKING PAPER – HUMPBACK SHRIMP PHASE 1

Date Submitted: October 10, 2001

Individual or group requesting advice:
(Fisheries Manager/Biologist, SWG, PSARC, Industry, Other stakeholder etc.)
Shrimp by trap, Shrimp by Trawl industry and managers

Proposed PSARC Presentation Date: Nov. 2002

Subject of Paper (title if developed): Assessment and management framework for Humpback Shrimp (P. hypsinotus)

Stock Assessment Lead Author: J. S. Dunham

Fisheries Management Author/Reviewer: Rick Harbo, Laurie Convey, Jim Morrison

Rational for request:
(What is the issue, what will it address, importance, etc.)
There is a need to develop a sound biological basis for the management of humpback fisheries and before targeted fisheries develop further. Management options for time, area openings and catch ceilings or reference points are needed.

Objective of Working Paper:
(To be developed by FM & StAD)
The objective of this program is to develop and test some of the assessment methodologies (direct biomass estimation, depletion studies, mark recapture) to determine the efficacy, cost, reliability and repeatability of the various techniques. This is a follow-up to the PSARC Phase 1 paper which outlined a number of management and assessment options for this type of directed fishery.

The deliverables from this program include a reliable assessment methodology for isolated fisheries. Estimates of the costs of management and assessment as it relates to the complexity of the fishery, so that industry is aware of the true costs. Estimates of the ecological impacts of the two fisheries techniques will be evaluated with respect to bycatch of other species and size and age selectivity as well as potential marketing of the various products from these fisheries. The results of this work will be the bases for a PSARC paper in Nov. 2002.

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

What are the areas that should be designated exclusive humpback shrimp fishing areas?

What are the target and limit reference points and the data requirements to assess and manage specific humpback areas and the associated costs to the fishery, i.e. a precautionary management system that addresses recruitment overfishing with clear decision rules.

What assessment methodologies for abundance measurement indices can be used for humpback shrimp?

What are the abiotic, biotic and fishery information requirements to assess the efficacy of the precautionary management approach, and can these be gathered in an experimental framework approach?

What are the compensatory and depensatory mechanisms that populations experience under various exploitation rates (e. g. 0% 15%, 30%, 45%)?

What environmental impacts result from various fishing technologies and what option best meets selective fishing criteria concerning bycatch and target species? Are there area-specific concerns that impact choice of gear?

What are the choices for management schemes in terms of yield per recruit modeling, the various fishing technologies employed and the market value of various products?

APPENDIX 2

COMMERCIAL EXPLOITATION HISTORY OF SHRIMP IN DRURY INLET

Trawl Gear

In the 1995/96 fishing season, commercial trawling activity became more prevalent in Drury Inlet; here, fishers generally targeted pink shrimp (Table 1). Extensive fishing activity occurred in Drury Inlet in 1996/97 when 103,316 kg of shrimp were removed by fishers, 26,826 kg being humpback shrimp (Table 1, Figure 1). Only small numbers of sidestripe shrimp (395 kg) and prawns (14 kg) have been removed with trawl gear since 1995.

Humpback shrimp were likely targeted during the 1995/96 and 2000/01 fishing seasons with trawl gear (Table 1). In 2001, prior to our surveys, 95 kg of humpback shrimp were collected in February and 1,476 kg in March.

Trap Gear

Throughout the 1990s, commercial trapping activity occurred in Drury Inlet; fishers generally targeted prawns, the highest catch was reported in the 2000/01 fishing season (Table 2). Humpback shrimp catches have become more prevalent since the 1998/99 season; since this time 4,776 kg of humpback shrimp have been harvested by trap gear. In 2001, prior to our surveys, 919 kg of humpback shrimp were harvested in May, 167 kg in June and 476 kg in July.

Summary

The commercial removal of humpback shrimp from Drury Inlet since 1990 by trawl and trap gear is 57,317 kg. Trawl gear was responsible for removing almost 92% of the shrimp. Trawlers used to target pink shrimp, but in recent years humpback shrimp have become increasingly important to the fishery. Trappers target prawns, and, in recent years, humpback shrimp as well. Over the last 4 years, or the lifespan of humpback shrimp, (i.e., since the 1998/99 fishing season) 11,979 kg of shrimp have been removed from Drury Inlet, 60.1% (7,203 kg) by trawl and 39.9% (4,776 kg) by trap gear. In 2001, just prior to our surveys, 3,134 kg of humpback shrimp were removed from the inlet between February and July; equal amounts were removed by both gear types.

Table 1. Weight (kg) of shrimp commercially exploited with trawl gear from Drury Inlet, 1995-2001. Data were obtained from commercial logbook records. Tow depth ranged, on average, between 45 and 64 m.

Year	Pink	Humpback	Coonstripe	Sidestripe	Prawn
1995/96	4,034	15,786	2,458	30	0
1996/97	73,926	26,826	2,203	361	0
1997/98	21,480	2,726	635	3	10
1998/99	8,119	642	0	0	0
1999/2000	10,024	4,735	590	0	0
2000/01	163	1,826	91	0	3
Total	117,747	52,541	5,977	395	14

Table 2. Weight (kg) of shrimp commercially exploited with trap gear from Drury Inlet, 1995-2001. Data were obtained from commercial logbook records.

Year	Prawn	Humpback	Coonstripe	Pink
1990/91	3,336	0	0	0
1991/92	8,955	0	0	0
1992/93	3,533	0	0	0
1993/94	3,082	0	0	0
1994/95	2,585	0	0	0
1995/96	4,708	0	0	0
1996/97	1,633	0	0	0
1997/98	6,146	0	0	0
1998/99	4,037	257	0	0
1999/2000	11,620	1,141	0	0
2000/01	21,870	1,817	0	0
2001/02	12,891	1,562	376	0
Total	84,399	4,776	376	0

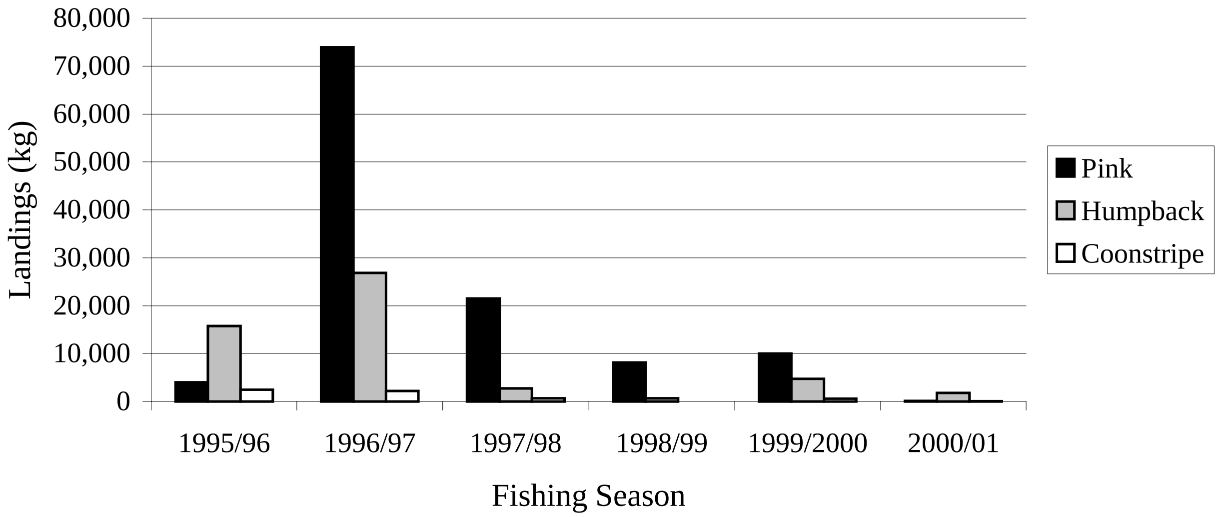


Figure 1. Commercial shrimp trawl exploitation history in Drury Inlet, 1995-2001.

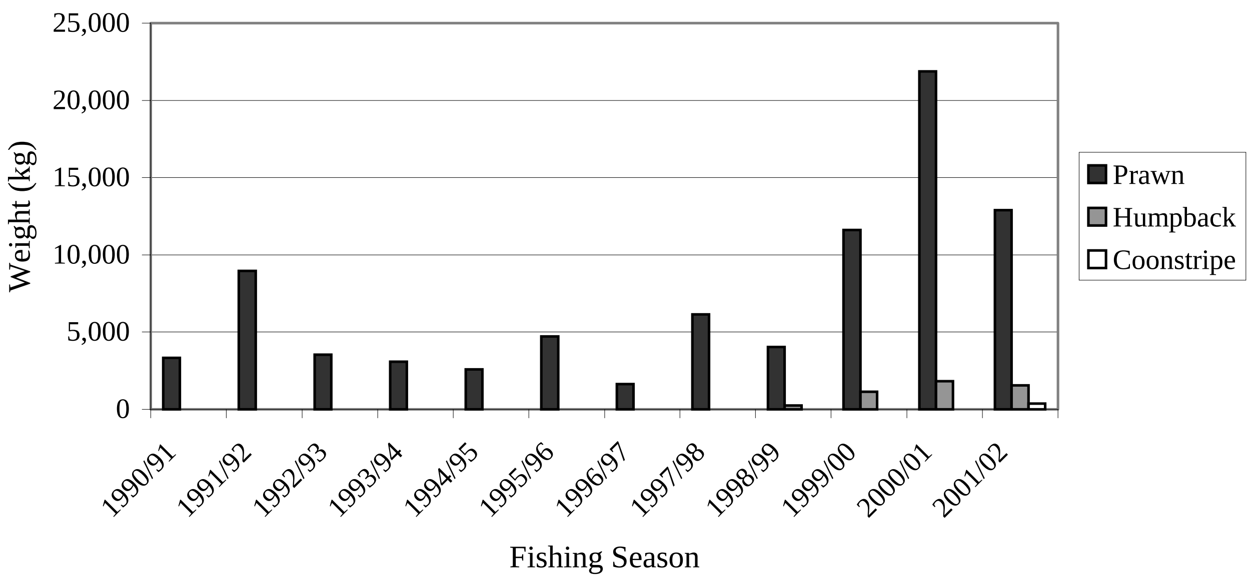


Figure 2. Commercial shrimp trap exploitation history in Drury Inlet, 1990-2001. No pink shrimp were harvested in traps.