Feasibility Study for Establishment of a Victorian Commercial Jellyfish Fishery

Russell J. Hudson, Natalie F. Bridge and Terence I. Walker

Project 92/125.31

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Natural Resources and Environment

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Table of Contents

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Principal Investigator: Terence I. Walker

Address: Marine and Freshwater Resources Institute
PO Box 114
Queenscliff Victoria 3225

Telephone: 03 5258 0111
Facsimile: 03 5258 0270

Objectives

(1) Provide order-of-magnitude estimates of jellyfish biomass in Port Phillip Bay.

(2) Investigate harvesting and on-board storage techniques.

(3) Trial jellyfish processing in Victoria and market testing in Asia and trial alternative drying techniques not involving alum.

Non Technical Summary

- Dried jellyfish bells are a highly regarded food item in many Asian countries. The bells, which are medusae with oral arms removed, are low in fat, cholesterol, and have medicinal benefits (Hsieh and Rudloe 1994). Large-sized bells are preferred by Japanese importers for display in sushi bars, while small-sized jellyfish are individually packaged whole or shredded in plastic or foil usually with condiments. Some small, lower valued jellyfish are currently imported into Australia from Asia. During 1988–92, the majority of consumer demand for this product was met by China, Malaysia and Thailand (Anon 1993a), but, more recently, increasing demand has led to interest in harvesting jellyfish from Australian waters.

- *Catostylus mosaicus* is one species, abundant in Australian waters, that can be processed cost-effectively and is suitable for the Asian markets. In Victoria, *C. mosaicus* occurs in high abundance in Port Phillip Bay, Westernport and Corner Inlet.

- This project was undertaken by the Marine and Freshwater Resources Institute (MAFRI), funded jointly by the Fisheries Research and Development Corporation, the Department of Natural Resources and Environment, Business Victoria, and China-Australia Aquatics Products Development Pty Ltd (CAAPD). The aim of the project was to assess the potential for a jellyfish fishery in Port Phillip Bay and to test export markets with Australian product. This final report is designed to meet the requirements of all four clients.

- In Port Phillip Bay, surveys indicated substantial populations of *C. mosaicus* in the northern and western coastal regions during February–May 1997. Biomass estimates for five strata in these regions ranged 48–1296 t, 9–806 t, 2323–7987 t, 2161–14805 t and 2004–17782 t. The mean bell diameter of *C. mosaicus* increased between January (18 cm) and April (30 cm) but then declined as condition deteriorated until mid-June (24 cm). The optimum time for harvesting appears to be during March–April, when the sizes of the bells are largest and the animals are in peak condition.

- Investigation of harvesting methods indicated jellyfish can be caught by either dip-nets or haul seine nets in sufficient quantities. Catch rates for dip-netting trials varied depending on aggregation density of *C. mosaicus* and weather conditions. Highest catch rates were obtained during calm conditions and when densities were at least 3–5 *C. mosaicus* per 100 m^2. Such densities are not uncommon, with 45 of the 180 transects recording densities >3 animals per 100 m^2.

- Dip-nets were more efficient at targeting commercial size (>30 cm) *C. mosaicus* than the beach seine. Only 20% of the animals caught by beach seine had bell diameters >30 cm. Whilst beach seining had by-catch of yellow-eye mullet (*Aldrichetta forsteri*), greenback flounder (*Rhombosolea tapirina*) and juvenile King George whiting (*Sillaginodes punctata*), dip-netting had no by-catch.

- Sufficient quantities of *C. mosaicus* can be caught in Port Phillip Bay and returned to shore before observable spoilage occurs, and time at sea can be extended by preliminary on-board processing of the animals.

- Traditional methods of drying jellyfish in Asia involve removing the oral arms and adding varying mixtures of common salt and alum to the bells until their moisture content is reduced from 97% to 65–70%. *Catostylus mosaicus* is not harvested in Asia and methods for drying this species have not been previously reported.

- CAAPD and MAFRI successfully produced dried *C. mosaicus* bells. Average shrinkage was about 14% of the bell diameter, with most of the shrinkage occurring at the edges. This shrinkage rate combined with the natural sizes of *C. mosaicus* reached during 1997 in Port Phillip Bay meant few dried bells reached a size of premium grade for the Asian market.

- Holes in the bell are another factor reducing the value of the bell. Several bells were observed with one or more holes or tears in the bells. It is unclear whether this was caused by handling or by bacteria or invertebrates such as isopods observed.

- Dried bells produced from other species of rhizostome jellyfish in China for export were larger and firmer, and had higher tensile strength than our dried *C. mosaicus* bells. Nevertheless, locally dried *C. mosaicus* bells were received favourably by Melbourne restauranteurs, but those presented to importers in Japan and Malaysia were rated lower than the value of products currently exported from China to Japan and Malaysia.

Acronyms

BGAPIC	Beijian Gaizhou Aquatic Products Industrial Corporation
CAAPD	China-Australia Aquatics Products Development Pty. Ltd
DNRE	Department of Natural Resources and Environment
FRDC	Fisheries Research Development Corporation
MAFRI	Marine and Freshwater Resource Institute

Background

Dried jellyfish is a highly regarded food item in many Asian countries. The bells, which are medusae with oral arms removed, are low in fat, cholesterol, and have medicinal benefits (Hsieh and Rudloe 1994). During 1988–92, the majority of consumer demand for this product was met by, China Malaysia and Thailand (Anon 1993a). Specific species included in this harvest are not known, however they were from the edible family Rhizostomeae. Most of the species occur in tropical and sub-tropical waters (Barnes 1986), but some can be found in the temperate waters of Australia (Shepherd and Thomas 1982). An increased demand for dried jellyfish, combined with inter-annual fluctuations in catch (Figure 1) and reported increasing pollution in Asian waters, has led to interest in harvesting rhizostome jellyfish from Australian waters.

Rhizostome jellyfish are distinguished by the absence of tentacles and the presence of branching oral arms with deep folds, where food is passed (Barnes 1986). The life history of some Rhizostomids e.g. *Stomolophus meleagris* is well documented (Calder 1982). *S. meleagris* develops from a fertilised egg to a free swimming planula that attaches itself to substrate and transforms into a sessile polyp. The polyp matures and, when conditions are favourable, releases free swimming ephyrae, which develop into mature adult medusa (Calder 1982). The term "jellyfish" is used throughout this report to refer to the adult medusae, unless stated otherwise.

Two rhizostome species occur in the temperate waters of south eastern Australia—*Pseudorhiza haeckeli* and *Catostylus mosaicus*. *P. haeckeli* is more common in offshore areas from around Australia (Shepherd and Thomas 1982). *C. mosaicus* (Plate 1) is an inshore species with an extensive distribution in eastern Australia, extending from the Torres Strait south to Victoria (Shepherd and Thomas 1982). It is highly likely that this species accounts for the majority of medusae found within a kilometre of shore in bays and enclosed water masses (Kingsford and Gillanders 1995). Little is known about the life history of either species, however Kingsford and Pitt (1997) identified a polyp stage in the life cycle of *C. mosaicus*, and Fancett (1986) identified *C. mosaicus* ephyrae from plankton tows in Port Phillip Bay. Rhizostome ephyrae are small (1.5–2.0 mm for *Stomolophus meleagris*) but rapidly grow to mature medusae (Kingsford and Gillanders 1995). It is at this mature stage that the jellyfish are harvested.

Jellyfish harvesting in Asia involves various methods, including set-nets, hand-nets, beach seines, and weirs (Omori 1981). Jellyfish are brought on board, stored in containers and taken back to shore for processing. To obtain the best results, processing of the jellyfish begins within 3 h of capture, so fishing trips are short (Subasinghe 1992). More recently in

China, as fishing boats operate further out to sea, ice has been used to maintain quality during longer trips (Peter Wright personal communication).

Processing methods for rhizostome jellyfish in Asia have been well described (Sloan and Gunn 1985; Subasinghe 1992; Hsieh and Rudloe 1994). The basic method involves the separation of the bell from the oral arms and viscera, which are usually discarded, although the arms can be dried as a low class product. The moisture content of the bell is reduced from about 97% to 65–75% through a series of steps, using a mixture of common salt (NaCl) and alum ($KAl(SO4)_2 .12H_2O$) to draw out the water. The alum is an important component in drying jellyfish (Huang 1988) as it serves as a disinfectant, hardening agent, (Huang 1988) and reduces the pH (Krishnan 1984). The concentration and ratio of salt to alum, the number of times they are added and the total processing time determines the quality of the end product. This process varies between species and processing companies. The dried jellyfish are classified into four grades based on the diameter of bell (Table 1) and, to a lesser extent, its colour.

Little work has been published on the catching, processing and marketing of jellyfish in western countries. Huang (1988) dried and evaluated the taste of cannonball jellyfish (*S. meleagris*) from the United States, with reasonable results. In contrast, Sloan and Gunn (1985) endeavoured to market *A. aurita* in southern British Columbia, but the product was not received well lacking desirable texture qualities. In Australia, Wootton *et al.* (1982) investigated different techniques of drying *C. mosaicus* bells caught in New South Wales waters. The product was rated as having reasonable qualities, but did not lead to the development of a commercial fishery.

Attempts at establishing commercial jellyfish fisheries in Australia have met with limited success. Two attempts to establish a fishery for *Phyllorhiza punctata* in the Swan River, Western Australia (Anon 1993b), and one attempt to establish a fishery for a *C. mosaicus* in New South Wales failed (M. Wootton personal communication). More recently, renewed interest in a *C. mosaicus* fishery within New South Wales estuaries led to the development of a management plan and a small number of fishing permits being issued. This culminated in a 10 t (wet weight) harvest which was dried and exported from New South Wales for marketing trials in Asia by the Taiga Food Company (The Australian, 13 April 1996). The success of these trials is unknown. No harvesting or processing has taken place in 1997, but resumption is expected in the near future (P. Dwyer personal communication). About an average of 30 t (dry weight) per month is imported into Sydney.

Large sized bells are preferred by Japanese importers for display in sushi bars, while smaller or lower valued jellyfish are individually packaged whole or shredded in plastic or foil and condiments may be included. These lower valued jellyfish are currently imported into Australia from Asia.

Need

In Victoria, China-Australia Aquatics Products Development Pty. Ltd (CAAPD), a subsidiary company of BGAPIC approached the Victorian Government during early 1996 as part of their feasibility study for processing jellyfish harvested locally and exporting dried bells to China.

Export of jellyfish from Australia requires a permit issued by Environment Australia under Section 10A of the Wildlife Protection (Regulation of Exports and Imports) Act 1982. One condition of such a permit to export jellyfish harvested from Victorian Proclaimed Waters is the preparation of a fishery management plan developed by DNRE. In addition, Business Victoria requires a business plan for the establishment of premises for processing jellyfish and any premises used for export have to be approved by the Australian Quarantine and Inspection Service.

Assessing the potential for a commercial jellyfish fishery in Victoria requires determining order-of-magnitude biomass estimates and appropriate harvesting and processing methods. During June 1996, CAAPD, DNRE, Business Victoria, FRDC and MAFRI jointly funded a project to provide this information.

Objectives

(1) Provide order-of-magnitude estimates of jellyfish biomass in Port Phillip Bay.

(2) Investigate harvesting and on-board storage techniques.

(3) Trial jellyfish processing in Victoria, export procedures, and market acceptance in Asia.

Introduction

Preliminary processing trials conducted by CAAPD on jellyfish species occurring in Victorian waters indicated that only *Catostylus mosaicus* can be processed cost-effectively and is suitable for the Asian markets. To obtain a broad overview of the presence or absence of *C. mosaicus* in the bays and inlets of Victoria, anecdotal information was collected from MAFRI staff and fishers (Appendix I). The anecdotal information indicated *C. mosaicus* was most abundant in Port Phillip Bay and, because the Bay is close to well established processing and exporting facilities, subsequent biomass estimates were made for only the Bay.

Little is published on the distribution or seasonality of *C. mosaicus* in Port Phillip Bay. Southcott (1971) commented that *C. mosaicus* is an estuarine species, but provided few other details. Fancett (1986) collected medusae samples from six sites in the Bay between Queenscliff and St Kilda but during the initial 12 months of sampling, no *C. mosaicus* were observed. Subsequent sampling indicated abundances of <1 ephyra per 1000 m^3 of water in northern region of the Bay.

Jellyfish often aggregate at particular depths during the day or under certain conditions. For example, Fancett and Jenkins (1988) acknowledge they may have underestimated the abundance of medusae (jellyfish) by towing a plankton net because the jellyfish aggregate near the surface on calm days. Species of the genus *Mastigias* aggregate in the top several meters during the day (Hamner and Hauri 1981), *A. aurita* exhibit diel migration (Yasuda 1969), *Cassiopea ndrosia* lie on the sea bed (Shepherd and Thomas 1982), and *Periphylla periphylla* occur below 60 m during the day and migrate to the surface during the night (Fossa 1992). These patterns have implications for the design of surveys for estimating biomass. Hamner and Hauri (1981) estimated biomass of *Mastigias* from the mean number per m^2 observed from vertical hauls. Van der Veer and Oorthuysen (1985) estimated the abundance of *A. aurita* in the western Wadden Sea by using double oblique hauls with a plankton net, while Garcia (1990) estimated the abundance of *P. punctata* using a beach seine to obtain volume sampled.

To develop an experimental design for estimating biomass in Bay, we had to undertake two pilot surveys and determine methods of sampling suitable to better gauge the distribution of *C. mosaicus* spatially and seasonally. We trialed aerial survey for observing and estimating jellyfish distribution and abundance in surface waters but found the method to be unreliable. In addition, underwater cameras and bongo nets available to us were found to be impractical sampling methods for assessing the vertical distribution of jellyfish in the water column (Appendix II). The two pilot surveys we conducted during March 1996–January 1997 indicated that *C. mosaicus* is most abundant in the shallow waters of northern Port Phillip Bay and aggregate near the surface on calm days (Appendix III).

Methods

The methods for the project address each objective separately.

Biomass Estimation

Port Phillip Bay is a large semi-enclosed bay with a surface area of approximately 1920 km^2 and water volume of about 25 $x10^9$ m^3 (Anon 1973) (Figure 2). From the entrance in the south, Port Phillip Bay opens to a wide basin extending about 60 km north to Hobsons Bay. To the west, the basin shallows along the Geelong Arm and extends into Corio Bay. The central basin is 20–24 m deep whereas the depth range in the Geelong Arm ranges 5–9 m. Annual sea surface temperatures range 10–22 ^{o}C. (Anon 1973), and salinity varies from 33.5 to 35.5 ppt (Longmore *et al.* 1996). The main freshwater inputs are from the Yarra–Maribyrnong River system, and Little, Werribee and Patterson River.

The survey design is based on the following findings of the anecdotal reports, sampling method trials and pilot surveys. (1) While *C. mosaicus* was rarely observed throughout the deeper waters of the Bay, it was often sighted in the northern parts of the Bay near shore. (2) Under calm conditions large numbers of *C. mosaicus* appeared in the surface waters where they are readily visible to observers on board research vessels at all times during the day. (3) The species most abundant during March–May. (4) The most suitable and cost-effective method for biomass estimation is to count jellyfish from on board a moving vessel under calm conditions. (5) The aggregations of *C. mosaicus* can be demarcated by approximate boundaries, past which few jellyfish can be observed.

The sampling strategy was to quantitatively sample the northern and western regions of Port Phillip Bay where aggregations of *C. mosaicus* had been previously observed and to avoid deploying available resources to broad regions of the Bay where aggregations jellyfish had not been previously observed. For initial sampling (early February 1997), three strata were assigned to the northern and western regions of the Bay but during mid-February, following sightings of jellyfish aggregations outside these strata, two additional strata were assigned to provide a total of five strata in these regions . The boundaries of the strata were determined by a MAFRI research vessel travelling a zigzag course along the edges of jellyfish aggregations. Initial boundaries of the strata drawn on a chart from vessel positions as a mix of bearing off selected landmarks and 1-m isobaths using

ARC/INFO GIS software. This GIS software could then be used to calculate the surface area of each stratum. Once the boundaries were fixed, 3–20 transect sites were randomly placed within each stratum using a grid map and a Microsoft Excel 6.0 random number generator before undertaking each sampling cruise.

The transects were traversed during calm weather between 0800 and 1600 Eastern Standard Time (EST) from MAFRI *RV Gratis* or a chartered vessel. Surveys were discontinued when wind speed exceeded 15 knots. The transect sites were located at sea using a Geographical Positioning System. For each transect, the vessel travelled at a constant speed and direction for 5 min while the number of jellyfish observed from the bow of the vessel was recorded. During the first cruise, two observers at the bow of the vessel identified and counted jellyfish observed within 5 m each side of the bow to give a transect width of 10 m while the vessel cruised at 3 knots. For the remaining cruises, a single observer counted jellyfish within 3 m each side of the bow to give a transect width of 6 m. The latitudes and longitudes were recorded for each of the start and finish positions for subsequent calculation of transect distance.

The total number of *Catostylus mosaicus* in each stratum for each cruise was estimated from the on board observer counts of jellyfish in the randomly placed transects, the total area of the transects and the total area of the stratum. The first step was to calculated the area of each transect as the product of the fixed distance each side of the vessel and the distance travelled by the vessel along the transect. The next step was to calculate the mean number of *C. mosaicus* and standard error per $100\ m^2$ of transect. Finally, total number of *C. mosaicus* within a stratum was estimated from multiplying the mean number $100\ m^2$ within the transects by the total surface area of the stratum divided by $100\ m^2$.

The size distribution of *C. mosaicus* within all strata was determined from those collected randomly during February–June 1997 using a dip-net or towed bongo net. Jellyfish were placed flat on a measuring board, and the distance between the edges of the bell measured to the nearest 0.5 cm to give the bell diameter. Bell diameter–frequency distributions and mean bell diameters were calculated for each month.

Weight–bell diameter relationships were determined from sampling *C. mosaicus*. Jellyfish were measured across the bells, weighed to provide a total wet weight (kg), and the bell weighed after removing the oral arms and viscera. Regressions of total weight against bell diameter and bell weight against total weight were calculated using power and linear regressions, respectively. Some jellyfish captured in May, and all those captured in June, were not included in the regression because deterioration of the oral arms caused a loss in weight.

Biomass in each stratum for each cruise was estimated from the estimate of total number of jellyfish, the appropriate monthly diameter–frequency distribution, and the total weight–bell diameter regression.

Jellyfish Harvesting and On-board Storage Technique.

During February–May 1997, four dip-netting trials and one beach seine trial were conducted at various localities in Port Phillip Bay to evaluate these methods for catching *C. mosaicus*. The first dip-netting trial had a skipper and two crew whereas the three remaining trials had a skipper and one crew. The procedure involved the skipper steering the boat while the crew caught C. mosaicus >27 cm bell diameter using dip-nets constructed with a 2.5-m handle, 56-cm radius hoop and 25-mm nylon-mesh webbing. The number of jellyfish or estimate of total weight and fishing effort (dip-netting time) were recorded. In addition, diameters of the bells were measured during two trials and weather conditions were noted during all trials. For beach seining, a commercial fisher set a 300-m long, 2-m deep and 25-mm mesh-size multi-filament beach seine set in 2.5-m deep water from a 5.7-m aluminium vessel. The seine net was set shortly after sunrise, when *C. mosaicus* were observed swimming mid-way in the water column. The time taken to set and haul the net was recorded along with the number of jellyfish caught, their bell-diameters and weather conditions.

Catch rates were expressed as total weight (kg) per person-hour for dip-netting and kg per haul for beach seining. For the dip-netting trials, density of *C. mosaicus* (number per 100 m^2) was available from the transect data, but for the beach seining trial, density had to be estimated by visual inspection.

To test on-board processing techniques, several jellyfish had their oral arms and viscera removed with a knife. The bells were washed in seawater and then rubbed on to both sides of the bell with a 19:1 salt-alum mixture. The time taken for this whole process and the time at sea were recorded separately. The bells were then processed on shore by Stages 2 and 3 of the method used by BGAPIC for drying rhizostome species in China. The final product was qualitatively compared with an imported bell that met Japanese market requirements. No taste testing was done.

Trials of Jellyfish, Processing, Exporting and Marketing.

CAAPD and MAFRI undertook trial drying of *C. mosaicus* during February–March 1997. While CAAPD has not publicly documented their processing techniques for reasons of commercial confidentiality. MAFRI undertook four processing trials where the method adopted by BGAPIC was modified by varying processing time (15 min–24 h) and alum concentration (0.5–2.0% by weight) in the first stage and amount of salt (15–25% by weight) in the second stage (Table 2).

Vacuum drying and air drying techniques were also trialed. For vacuum drying, 50% of the *C. mosaicus* bells were rubbed with a 19:1 salt-alum mixture and the remaining 50% left untreated. The pressure in the vacuum tank was reduced from 2600 kpa to 800 kpa over 1 h and then maintained at that pressure for 48 h. Temperature inside the tank ranged 20–30°C. For air drying , 20 jellyfish bells were placed inside a Majors Air Dryer for 36 h at 35–45°C. Four jellyfish were rubbed with a salt-alum (19:1) mixture, and one sliced into 2 cm strips. The remaining jellyfish had no treatment. The dried bells were compared with a Grade I bell imported from China on the basis of appearance, strength and texture.

Results

Biomass Estimation

Catostylus mosaicus were found in large aggregations in the northern and western regions of Port Phillip Bay during February–May 1997. Initially, three strata (Mordialloc, Geelong

Arm and Hobsons Bay) were defined in these regions for survey purposes. The outer boundaries for the Mordialloc and Geelong Arm Strata were defined by the 8-m isobath. The outer boundary for the Hobsons Bay Stratum was set as an east-west line about 1 km south of the Yarra River mouth. By late February, anecdotal reports indicated the presence of jellyfish in Corio Bay and the Outer Harbour, and these areas were then included as additional strata in the survey (Figure 2). In the remaining inshore areas of the Bay, very few *C. mosaicus* were observed, with the one exception of a single small aggregation observed near Portarlington. Survey of this area indicated the aggregation was present during the first week of February but was absent by mid-February.

During April, field sampling verified anecdotal reports that *C. mosaicus* no longer occurred in waters less than 2 m. Hence, waters <2 m were excluded from sampling and the analyses. For similar reasons, waters <4 m were excluded for May and June. Total areas of the strata for the appropriate depth ranges were calculated for each month (Table 3). The maximum area over all strata sampled at any time was about 11% of Port Phillip Bay.

A total of 19,528 *C. mosaicus* were counted in a total of 180 transects completed during 13 cruises between 7 February and 20 June 1997. The surface area over all transects covered 644×10^3 m^2, when adjusted for depth of visibility gave a water volume of $2{,}298 \times 10^3$ m^3 (Figure 7).

A total of 415 *C. mosaicus* were measured across the bells. The smallest animal had a bell diameter of 5.5 cm (March) and the largest animal had a bell diameter of 42.0 cm (April). Diameter-frequency distributions are presented for each month during February–June (Figure 3). During February, bell diameter ranged 7–36 cm. During March, the proportion of animals <15 cm declined and the proportion of jellyfish >30 cm increased from 6% to nearly 50%. While the largest animals measured were captured during April, the proportion of animals >30 cm declined from 50% to 47%. This decline continued as animals >35 cm disappeared during May and animals >30 cm disappeared during June (Figure 3). In summary, mean bell diameter increased at a constant rate from January to March then slowed markedly during April before declining during May and June (Figure 4).

During February–April, samples of *C. mosaicus* were weighed and measured to provide total weight–bell diameter and bell weight–total weight relationships. The smallest animal (7.5 cm bell diameter) weighed 0.03 kg and the largest animal (41.5 cm) weighed 8.1 kg. A log-log regression of total wet weight (tw kg) against bell diameter (d cm) for 112 animals gave the relationship $tw = 1.01 \times 10^{-4} \times d^{3.07}$ ($r^2 = 0.94$, Figure 5). A linear regression of bell wet weight (bw kg) against total wet weight for 41 animals gave the relationship $bw = -0.005 + 0.544 \times tw$ ($r^2 = 0.97$, Figure 6).

Because of the low number of days when weather conditions allowed sampling and the need to alter strata boundaries between cruises, no attempt was made to estimate the total number or biomass of *C mosaicus* for the whole of Port Phillip Bay. The mean number of *C. mosaicus* observed per 100 m^2 (± s.e.) and estimates of total number and biomass are presented for each stratum in Table 4 and Figure 8. For March, the results for Corio Bay, the Outer Harbour and Geelong Arm Strata had to be excluded from the analyses because dredging a shipping channel in the Outer Harbour Stratum reduced visibility at the time of when field sampling.

In the Geelong Arm Stratum, the estimates of number of *C. mosaicus* peaked during February, declined, then stabilised from the end of February to early April, before declining again during May. The biomass peaked in February at 14,805 t and again in early April at 9,839 t when mean bell diameter was highest (Figure 4). The biomass declined rapidly during May from 4,322 t to 2,161 t. During May, most of the remaining jellyfish in Geelong Arm Stratum were observed at the south-western end and an isolated aggregation was observed in the north. While the number of animals declined by 30%, the biomass declined by nearly 50% (Figure 8).

In the other strata the time series of data are less complete. Estimated biomass peaked during April in both the Corio Bay Stratum (7987 t) and the Outer Harbour Stratum (17,782 t). The Hobsons Bay and Mordialloc Strata supported smaller populations of *C. mosaicus* reflecting the smaller area of the strata (Table 3). The highest estimates were observed during mid-February; 806 t in Hobsons Bay Stratum, and 1296 t in Mordialloc Stratum. Biomass subsequently declined rapidly during February in both strata and by May had declined to 3% in the Hobsons Bay Stratum and to 50% in Mordialloc Stratum.

The highly clumped distribution of *C. mosaicus* gave large variation in the transect counts and hence high standard errors and uncertainty in the estimates. For example, the two largest biomass estimates—17,782 t for the Outer Harbour Stratum during April and 14,805 t for the Geelong Arm Stratum during February—have particularly high uncertainty (Figure 8) caused by large ranges in the transect counts of 1.85–47.44 and 0.93–25.68 per $100m^2$ for these two strata, respectively. One transect contributed 59% of the total number of jellyfish observed for the Geelong Arm Stratum.

Jellyfish Harvesting and On-board Storage Technique.

Catch rates for the four dip-netting trials varied 108–250 kg per person-h and the catch rate for the beach seine was 56 kg per haul (Table 5). The highest catch rates (216–256 kg per person-h) obtained were during calm conditions when *C. mosaicus* aggregated near the surface. The lowest catch rate of 108 kg per person-h was taken in a 15-knot southerly wind, when the animals were >1 m below the surface making dip-netting difficult. The low density of *C. mosaicus* (3 per $100m^2$) also contributed to time spent manoeuvring the vessel. Having two people dip-netting did not contribute to a higher harvesting rate (128 kg/person-h), as the skipper could only manoeuvre the vessel so one person can dip-net.

Dip-nets were more efficient at targeting commercial size (>30 cm) *C. mosaicus* than the beach seine. Only 20% of the animals caught by beach seine had bell diameters >30 cm. Whilst beach seining had by-catch of yellow-eye mullet (*Aldrichetta forsteri*), greenback flounder (*Rhombosolea tapirina*) and juvenile King George whiting (*Sillaginodes punctata*), dip-netting had none.

For the on board storage trial, the average time taken to remove oral arms and viscera from *C. mosaicus* was 30 sec per animal and a further 15 sec was required to rub a salt-alum mixture into the bell. The bells remained at sea for 3 h before being processed. The quality of the dried bells produced from on board storage (Table 6) were indistinguishable from those produced from on shore MAFRI processing (see below).

Trials of Jellyfish Processing, Exporting and Marketing.

The common salt-alum processing method was better than the vacuum tank and air drying methods for drying *C. mosaicus* bells. The vacuum tank method removed insufficient moisture from *C. mosaicus* bells, whereas the air drying method removed too much moisture and produced dried bells that were too thin. Salt concentration was a crucial factor in drying the bells common salt-alum process method.

In the first (Trial 1) of the four processing trials conducted by MAFRI, where an attempt was made to repeat the method used by BGAPIC, the dried bells easily tore and were too soft because insufficient salt was added during the second stage. These bells were not rated and, in subsequent trials, the amount of salt was increased from 17% to 20%.

Varying soaking time in a fixed concentration of alum (Trial 2) had little effect on the physical appearance or strength of a dried bell. Long soaking periods (Test 2.4) produced paler coloured dried bells (Table 6), as they appeared to loose too much moisture with shrivelling at the outer rims. The surface texture of the outer part of the bells in all trials was tessellated, whereas the surface texture of imported bells was smooth. Also the tensile strength of *C. mosaicus* bells was less than that of the imported bells.

Varying alum concentration for a fixed period of 45 min (Trial 3) had similar effects on appearance, tensile strength and colour as Trial 2. The dried weights were fairly consistent and represented approximately a 90% reduction in bell weight (Table 6).

Varying the concentration of the common salt in the second stage of processing produced a range in dried bell quality (Table 6). Drying with only 18% salt (Test 3) and 15% salt (Test 4), produced bells that were not firm, easily torn, of unacceptable odour, and too moist. Tests 1 and 2 produced better dried bells than Tests 3 and 4.

Dried *C. mosaicus* bells from the salt-alum trials had an average shrinkage of about 14% in diameter, with most of the shrinkage occurring at the edges. This shrinkage rate combined with the natural sizes of *C. mosaicus* reached during 1997 in Port Phillip Bay meant few dried bells reached a size of premium grade for the Asian market.

Holes in the bell are another factor reducing the value of the bell. Several bells were observed with one or more holes or tears in the bells. It is unclear whether this was caused by handling or by bacteria or invertebrates such as isopods observed. Classes 2 and 3 allow for two holes within the bell (Table 1).

Catostylus mosaicus bells dried by CAAPD and MAFRI were received favourably by Melbourne restauranteurs (J. Chan, personal communication), but those presented to importers in Japan and Malaysia were rated lower than the value of products currently exported from China to Japan and Malaysia. Dried bells produced from other species of rhizostome jellyfish in China for export (Plate 5) were larger and firmer, and had higher tensile strength than our dried *C. mosaicus* bells.

Discussion

The results from all our trials indicate potential for a *C. mosaicus* fishery within Victorian waters. The jellyfish are abundant in Port Phillip Bay and can easily be caught by dip-net or surrounding haul seine by existing licensed fishers with little capital outlay. The minimum estimate of 2161 t within the Geelong Arm, alone, represents about 0.7% of the total world production in 1992 (Anon 1993a). However, the processing techniques for *C. mosaicus* need to be improved, and the marketing and export procedures developed.

Biomass Estimation

Despite the limitations on the intensity and frequency of our sampling, several important conclusions can be drawn about *C. mosaicus* from our data and synthesis of other available information. (1) The species occurs in Port Phillip Bay and several other inshore areas of Victoria such as Westernport and Corner Inlet. (2) Whilst the populations are extremely patchy, at times C. mosaicus form dense aggregations large enough to provide a fishery. (3) Within Port Phillip Bay the species aggregated near shore in the northern and western regions of the Bay, (4) The species exhibited considerable movement within the Bay over a 2–3-month period. (5) The occurrence of the species is highly seasonal within the Bay, they first appear January–February and remain until late June. (6) Rapid growth rates produce a very high biomass within 1–2 months. (7) Following a peak in April, biomass declines rapidly with onset of senescence exhibited through deterioration of oral arms, reduction in size and widespread mortality.

The patchy distribution and difficulty in defining the boundaries of the sampling strata cause high uncertainty in the biomass estimates and require much more intensive sampling to improve precision of the estimates (e.g. reduced standard errors). Some of the uncertainty is from those parts of the population unsighted in water column, outside the strata boundaries, and unsurveyed in the 0–1 m isobathymetric interval. Given Kingsford and Pitt (1997) found that 80–90% of several *C. mosaicus* populations in New South Wales were located within 1 m of the surface on calm days, it is likely we sighted most of the population from the surface. Random visual checks indicated negligible *C. mosaicus* occurred outside the strata boundaries, which is consistent with the observation of Kingsford and Gillanders (1995) that the majority of the population is found within 1 km of shore. Our inability to survey waters within the 0–1 m isobathymetric interval (about 10% of the total strata area) had the potential to underestimate biomass.

Rapid growth (Garcia 1990, Möller 1980) and migratory life cycles might explain the sudden appearance of reasonably sized *C. mosaicus* in Port Phillip Bay during February 1997. Van der Veer and Oortuysen (1985) observed high growth rates but noted that the final bell size of *A. aurita* varies from year to year, for which Möller (1980) suggested that either water temperature or food supply was responsible. Gröndahl (1988), on the other hand, concluded that the presence of *Cyanea lamarckii* in Gullmar Fjord, Sweden, is dependent on immigration from the North Sea because it does not reproduce within the fjord, but although *C. capillata* migrates into the fjord it also reproduces within the fjord. Van der Veer and Oortuysen (1985) found *A. aurita* moves from the West Wadden Sea into the North Sea as it matures, but to complete its life cycle the planula larvae would have to drift back into the inner parts of the Wadden Sea. Our study provides evidence of rapid growth of *C. mosaicus* during February–April, but the lack of sightings of very small animals before February provides some evidence for immigration as the cause of the sudden appearance of larger animals during February.

The rapid changes in relative abundance of *C. mosaicus* between strata might be partly explained by movement between strata. For example, the weak westerly tidal current through the Outer Harbour and most of the Geelong Arm Strata (Anon 1973) might slowly move the animals between thee strata. In New South Wales, Kingsford (unpublished data) observed a large proportion of *C. mosaicus* orientated towards currents generated by winds or waves. In addition, some of the increase in number of *C. mosaicus* from February to April might have resulted from *C. mosaicus* moving from some of the inshore waters too shallow for sampling to the deeper surveyed areas of the strata.

In weak currents, *Catostylus mosaicus* have the ability to hold position in the water, a characteristic common in Rhizostomids (Kingsford and Gillanders 1995). Loss of this ability through deterioration of the oral arms and poor condition might explain why part of the population drifted across the strata boundaries. This is consistent with the rapid decline in the Geelong Arm and Outer Harbour Strata where a large proportion of their boundaries are exposed to tidal currents. Conversely, the limited water exchange occurring between Corio Bay and the rest of Port Phillip Bay (Anon 1973) might explain why the rate of depletion within this strata was slower.

The reduction in size and condition of free swimming animals and the occurrence of large numbers of dead *C. mosaicus* observed on the beaches during early May are indicative of high mortality following peak abundance in Port Phillip Bay during April. This is a pattern similar to other species of jellyfish in temperate waters. Brewer (1989) observed the disappearance of *Cyanea* species from the Niantic River over winter when the temperature of the river drops to –7 °C. Möller (1980) observed a size reduction of *A. aurita* during autumn following spawning. The absence of *C. mosaicus* in Port Phillip Bay from winter onwards during 1997 differs from that observed by Kingsford and Pitt (1997), where the species is present throughout the year. Fancett (1986) suggests the species is at its southern limit in the Bay and the low water temperatures experienced in winter cause the decline.

Jellyfish Harvesting and On-board Storage Technique.

Our catch rates of 108–256 kg per person-h for dip-netting *C. mosaicus* are substantially higher than those reported by Sloan and Gunn (1985) (15–180 kg per person-h) for *A. aurita* in British Columbia. The present study suggests that an efficient dip-netting operation requires a density of at least 3 jellyfish per 100 m^2 and calm weather to achieve productivity of at least 130 kg per person-h. The occurrence of this density is not uncommon. Of our 180 transects, 45 had densities greater than 3 animals per 100m^2 during February and April. Calm conditions do not occur consistently in Port Phillip Bay. South-westerly and strong south-easterly winds can occur frequently during summer, limiting fishing days in most strata. In the Corio Bay Stratum, it is sheltered from prevailing westerly wind and dip-netting can be performed over a wider range of conditions

Whilst catch rates for our haul seining were low, Sloan and Gunn (1985) recorded a catch rate of 240 kg /h for a haul seining operation. In Port Phillip Bay, beach seines can catch large aggregations of jellyfish (Plate 3). While large catches can be taken, significant amount of time may be spent sorting the jellyfish by size. The advantage of haul seine nets over dip-netting is that they can be deployed over a wider range of weather conditions and the position of the jellyfish in the water column is not as critical. However, it is not known whether the bell of the jellyfish is damaged when hauling large catches.

The techniques we developed to process jellyfish on board were successful, and can be used to extend time at sea, and reduce the volume of product that needs to be handled. Although we only stored the bells at sea for 3 h, longer storage times are expected . On board storage of *C. mosaicus* bells increases the efficiency of the fishery. By adopting some limited processing at sea, oral arms and viscera can discarded at sea to avoid costly disposal on land. From observations of dead *C. mosaicus* in tanks at MAFRI, it takes less than a week for the jellyfish to decompose.

Trials of Jellyfish Processing, Exporting and Marketing.

CAAPD and MAFRI successfully dried *C. mosaicus* bells. CAAPD staff were able to process and dry a *C. mosaicus* bell to what is regarded by Asian importers as 50% the value of Grade I dried bells currently sold in Asia. CAAPD staff were confident with further refinement, *C. mosaicus* can be dried to a product acceptable to Asian markets. The jellyfish market in Japan has very specific quality requirements, with certain tastes, texture and a "crunch" when bitten (Sloan and Gunn 1985). The lack of "crunch" in the bells from the present study is consistent with those produced by Sloan and Gunn (1985) with *A. aurita*, and by Wootton *et al.* (1982).

Air drying jellyfish produced a dried bell that did not meet current Asian market demands but was superior to that produced by Wootton *et al.* (1982) using salt alone. Because small amounts of aluminium is retained within the dried bell from processing and the link of aluminium to Alzheimers Disease health concerns have been raised (Hsieh and Rudloe 1994). Developing an alternative drying technique would have considerable marketing advantages. Developing such a product combined with the perception in Asia of a clean environment in Australia could create a niche market for Victorian jellyfish. Further research is needed in this area.

The size distribution of the *C. mosaicus* population in Port Phillip Bay has important implications for the fishery. Jellyfish need to obtain a diameter of at least 30 cm to be of commercial value (Jess Chan personal communication). During all sampling periods at least 50% of the population was less than 30 cm in diameter. It is not clear whether the smaller jellyfish resulted from variations in growth rate or recruitment times. Nevertheless, the results suggest that March and April would be the optimum times for harvesting, as the larger jellyfish would obtain a higher grade. This differs from New South Wales where optimum size occurred in spring (Kingsford and Gillanders 1995).

Conclusion

Four conclusions are drawn from our survey estimates of abundance. (1) Populations of *C. mosaicus* are not wide spread through out Port Phillip Bay but aggregate inshore in the northern and western regions of the bay. (2) From February to April the biomass in the Mordialloc Stratum ranged 76–1296 t, Hobsons Bay Stratum ranged 385–806 t, Geelong Arm Stratum ranged 4191–14805 t, Corio Bay Stratum ranged 2323–7987 t and the Outer Harbour ranged 9376–17782 t. (3) Biomass peaked in the Mordialloc, Hobsons Bay and Geelong Arm Strata during February, and peaked in Corio Bay and Outer Harbour during

April. (4) The population of *C. mosaicus* in Port Phillip Bay could have provided a jellyfish fishery during the period from February to April 1997.

Three conclusions are drawn from our study of harvesting techniques and on-board storage techniques. (1) Jellyfish can be easily caught by dip-netting or surrounding haul seine net. (2) Dip-netting is a preferred harvesting method as there is no by-catch and larger animals are easily targeted. (3) On-board storage techniques were developed though sufficient quantities of jellyfish can be caught before spoilage begins.

Five conclusions are drawn from our study into jellyfish processing and market testing techniques. (1) *C. mosaicus* can be dried using the salt-alum method to produce a product that is acceptable to Asian markets. (2) The drying process has not been fully refined and needs further experimentation. (3) The average shrinkage of the bell during processing is approximately 14% indicating few *C. mosaicus* caught in Port Phillip Bay would make the premium grade. (4) Further market testing needs to be undertaken. (5) Vacuum and air drying methods were not successful in drying jellyfish.

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Benefits

The Victorian fishing industry will benefit directly from development of the jellyfish resource to supplement existing fisheries, and from additional employment to process the product. The Victorian and Australian communities will benefit through supply of an additional food and export revenue.

Intellectual Property

Intellectual property associated with data produced from the project will be shared equally by the Fisheries Research and Development Corporation, the Victorian Department of Natural Resources and Environment, Business Victoria and the Marine and Freshwater Resources Institute.

Further Development

In the short-term, it is envisaged a processing plant will be developed to process 1500 tonnes wet weight of *C. mosaicus* per year (to be reviewed in 1998/99) from Victorian bays and inlets during 1998 and 1999 under a developmental fishery status. The developmental fishery will be managed by a fishery management plan developed by Fisheries Victoria, Department of Natural Resources and Environment. A reporting system will be developed for recording commercial catch and effort data.

A full commercial fishery will be announced in 2000 and an appropriate TAC will be set and units of quota sold on the open market by Fisheries Victoria.

Staff

Position, period and percentage of time on project are listed for each staff member

Terry Walker	Principal Scientist	1 Jul 1996-30 Jun 1997	5%
Russell Hudson	Fisheries Scientist	1 Jul 1996-30 Jun 1997	40%
Natalie Bridge	Technical Officer	1 Feb 1997 30 Jun 1997	30%
Ken Smith	Technical Officer	1 Jul 1996- 30 Jan 1997	5%

Final Cost

Budget item	Grant $	Expenditure $
Salaries	21750	38670
Operating expenses	33250	20200
Travelling expenses	1000	135
Capital items	4000	995
Total	60000	60000

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Plate 1. *Catostylus mosaicus.*

Plate 2. Dip-netting for *Catostylus mosaicus.*

Plate 3. *Catostylus mosaicus* caught by seine net (photograph courtesy Steve Lyons).

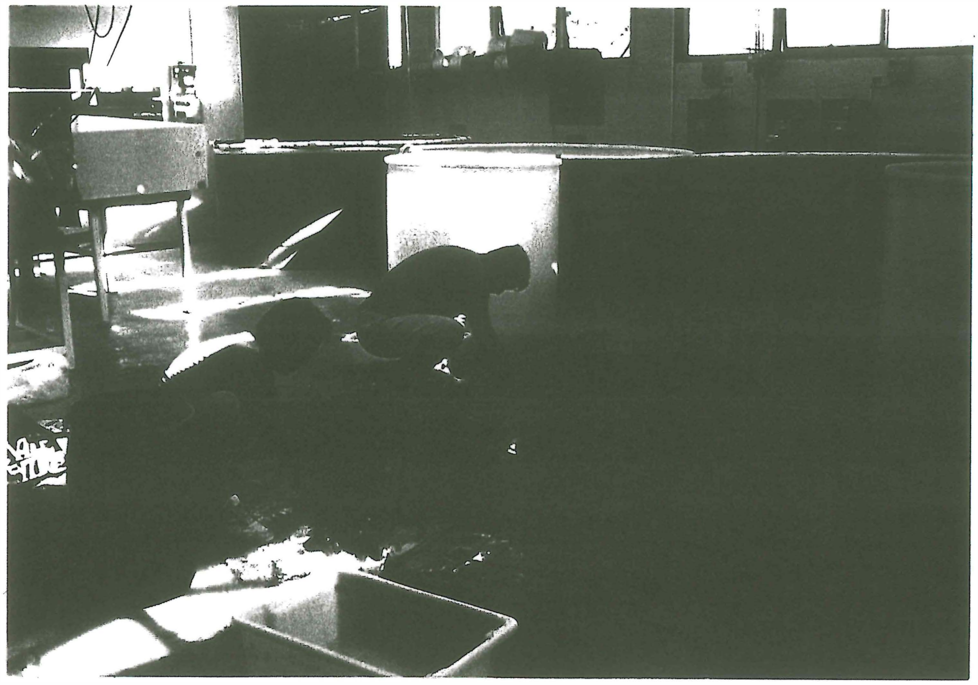


Plate 4. *Catostylus mosaicus* processing begins with removal of oral arms and viscera.

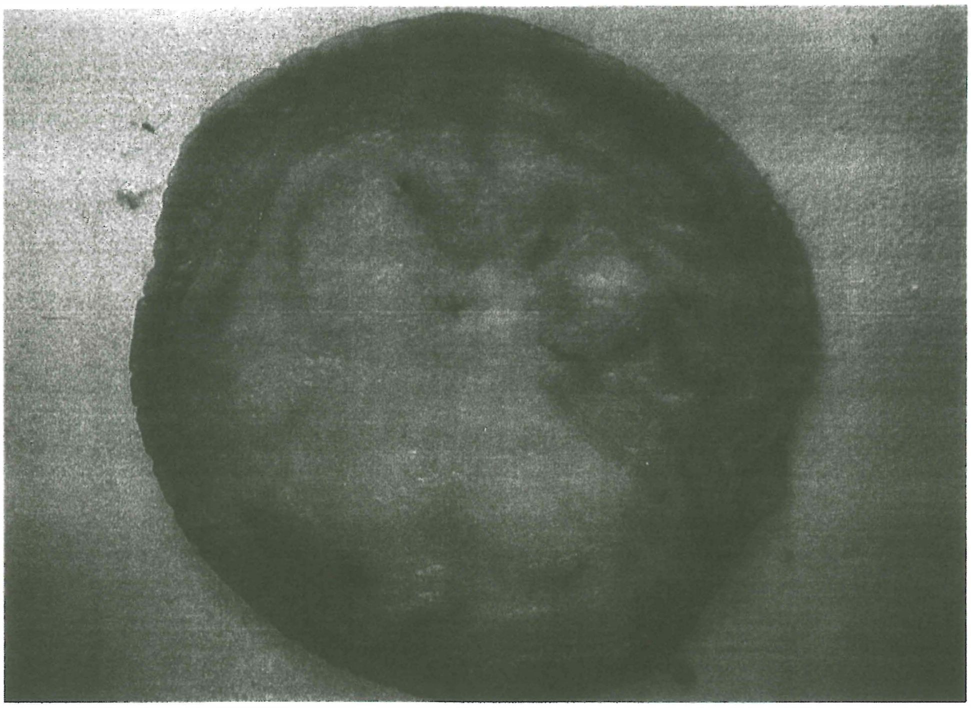


Plate 5. Dried *Catostylus mosaicus* produced by Beijian Gaizhou Aquatic Products Industrial Corporation.

Table 1. Classification of jellyfish bells[A]

Grade	Dried bell diameter (cm)	No. of holes allowed in bell
I	>35	0
II	30–34	2
III	20–29	2
IV	15–19	2

[A]Export standard of jellyfish in China.

Table 2. Processing tests undertaken by MAFRI with BGAPIC[A] method

Trial no.	Test no.	Process		
		Concentration of alum first stage (%)	Time soaked in alum first stage (h)	Concentration of salt second stage (%)
1	1.1	0.6	1.0	17
2	2.1	0.6	0.25	20
	2.2	0.6	0.50	20
	2.3	0.6	1.0	20
	2.4	0.6	1.5	20
3	3.1	0.5	0.75	20
	3.2	1.0	0.75	20
	3.3	1.5	0.75	20
	3.4	2.0	0.75	20
4	4.1	0.6	24.0	25
	4.2	0.6	24.0	22
	4.3	0.6	24.0	18
	4.4	0.6	24.0	15

[A] Beijian Gaizhou Aquatic Products Industrial Corporation.

Table 3. Total area of each stratum sampled in Port Phillip Bay

Strata	Stratum area (km^2) and depth range[A] surveyed.				
	February 1-8	March 1-8	April 2-8	May 4-8	June 4-8
Corio Bay	35.85	35.85	32.94	25.72	25.72
Hobsons Bay	8.06			4.98	
Geelong Arm	122.30	122.30	108.32	80.2	
MordiallocB	10.69	10.69		8.96	
Outer Harbour		32.95	30.67	27.33	27.33

[A]Corio Bay, Hobsons Bay, Geelong Arm, and Outer Harbour deeper waters were surveyed. [B]During May the depth range was extended to 11m'.

Table 4. Estimates of abundance of *Catostylus mosaicus* during February–June 1997

Stratum/ Date	Total stratum area (km^2)	No. of transects	Transect area/ stratum area (%)	No. of *C. mosaicus* per 100m^2 ± se	No. of *C. mosaicus* (thousands)	Biomass (tonnes)
Hobsons Bay						
15 Feb	8.1	4	0.09	5.17± 2.60	417	806
28 Feb	8.1	3	0.16	2.48± 1.23	199	385
12 May	5.0	4	0.14	0.07± 0.07	3	9
Mordialloc						
15 Feb	10.7	6	0.33	6.21± 4.66	664	1296
19 Feb	10.7	6	0.36	0.54± 0.45	58	1117
28 Feb	10.7	6	0.26	0.37± 0.17	39	76
12 May	9.0	12	0.13	0.19± 0.05	17	48
Geelong Arm						
15 Feb	122.3	8	0.02	6.26± 2.95	7656	14805
19 Feb	122.3	9	0.03	1.77± 0.59	2167	4191
28 Feb	122.3	6	0.03	2.04± 0.49	2492	4775
26 Mar	122.3	19	0.05	1.06± 0.34	ne[B]	ne[B]
11 Apr	108.3	17	0.05	2.24± 0.88	2426	9839
17 Apr	108.3	9	0.04	0.98± 0.53	1066	4322
16 May	80.2	16	0.02	0.65± 0.31	749	2161
Corio Bay						
28 Feb	35.9	3	0.07	3.35± 2.41	1201	2323
26 Mar	35.9	1	0.01	0.50±	ne[B]	ne[B]
11 Apr	32.9	2	0.01	63.8± 4.12	ne[A]	ne[A]
17 Apr	32.9	7	0.05	5.98 ± 1.22	1969	7987
16 May	25.7	5	0.03	5.14 ± 2.98	1322	3816
20 Jun	25.7	5	0.03	0.57 ± 0.33	147	423
Outer Harbour						
26 Mar	32.9	4	0.02	3.39 ± 1.29	ne[B]	ne[B]
11 Apr	30.7	5	0.01	14.30 ± 8.64	4385	17782
17 Apr	30.7	9	0.02	7.54 ± 3.38	2312	9376
16 May	27.3	3	0.01	2.54 ± 1.15	694	2004
20 Jun	27.3	6	0.02	0.12 ± 0.06	33	94

[A]Not estimated beacause the number of transects was less than 3. [B]Not estimated due to dredging effect.

Table 5. Catch rates of *Catostylus mosaicus* by dip-net and beach seine in Port Phillip Bay during February–May 1997

Date	Method	Approximate density (no. per 100m^3)	No. crew[A]	No. of jellyfish caught	Diameter range (cm)	Total weight (kg)	Time fishing (min)	Catch per unit effort (kg/person–h)
14 Feb	Dip-net	8	2	81	nd	214	50	128
19 Feb	Dip-net	3	1	20	nd	54	30	108
6 Mar	Dip-net	5	1	nd	25-35	270	75	216
24 Mar	Beach seine	<1	nd	20	8-34	56	90	56[B]
16 May	Dip-net	8	1	54	16-34	146	35	250

nd, No data. [A]not including skipper. [B]Expressed as kg/haul.

Table 6. Details of MAFRI processing trials and on board storage trial

Trial	Test no.	Wet mean diameter (mm)	Dried mean diameter (mm)	Initial mean bell weight (kg)	Final mean bell weight (kg)	Highest possible grade	Comparison with Chinese product[A]
1	1.1	nd	nd	nd	nd	nd	nd
2	2.1	310	267	nd	0.10	III	D
	2.2	310	280	nd	0.10	III	D
	2.3	317	256	nd	0.12	II	D
	2.4	328	278	nd	0.19	III	C
3	3.1	299	252	nd	0.06	II	C
	3.2	310	257	nd	0.08	III	D
	3.3	311	268	nd	0.14	II	C
	3.4	309	263	nd	0.16	II	D
4	4.1	239	216	1.13	0.10	III	D
	4.2	247	212	1.13	0.11	III	D
	4.3	252	210	1.16	0.10	III	D
	4.4	338	287	2.34	0.18	II	E
OB[B]		300	265	nd	nd	II	D
CAAPD[C]		nd	265	nd	0.09	II	B/C

nd, no data. [A]Jellyfish were rated A-E compared to imported Grade I dried bell, A being identical. [B]On board processing. [C]Processing by CAAPD.

Figure 1. World catch (tonnes) of jellyfish during 1982–1992 (Anon 1993a).

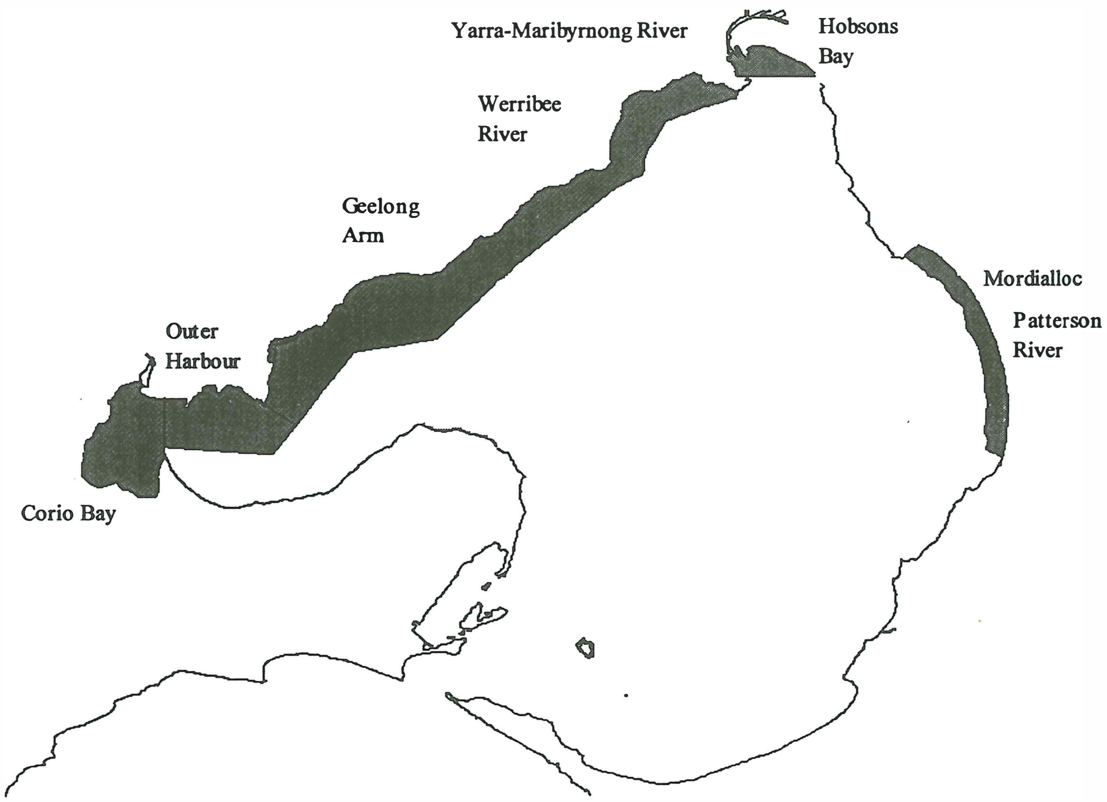


Figure 2. Port Phillip Bay strata.

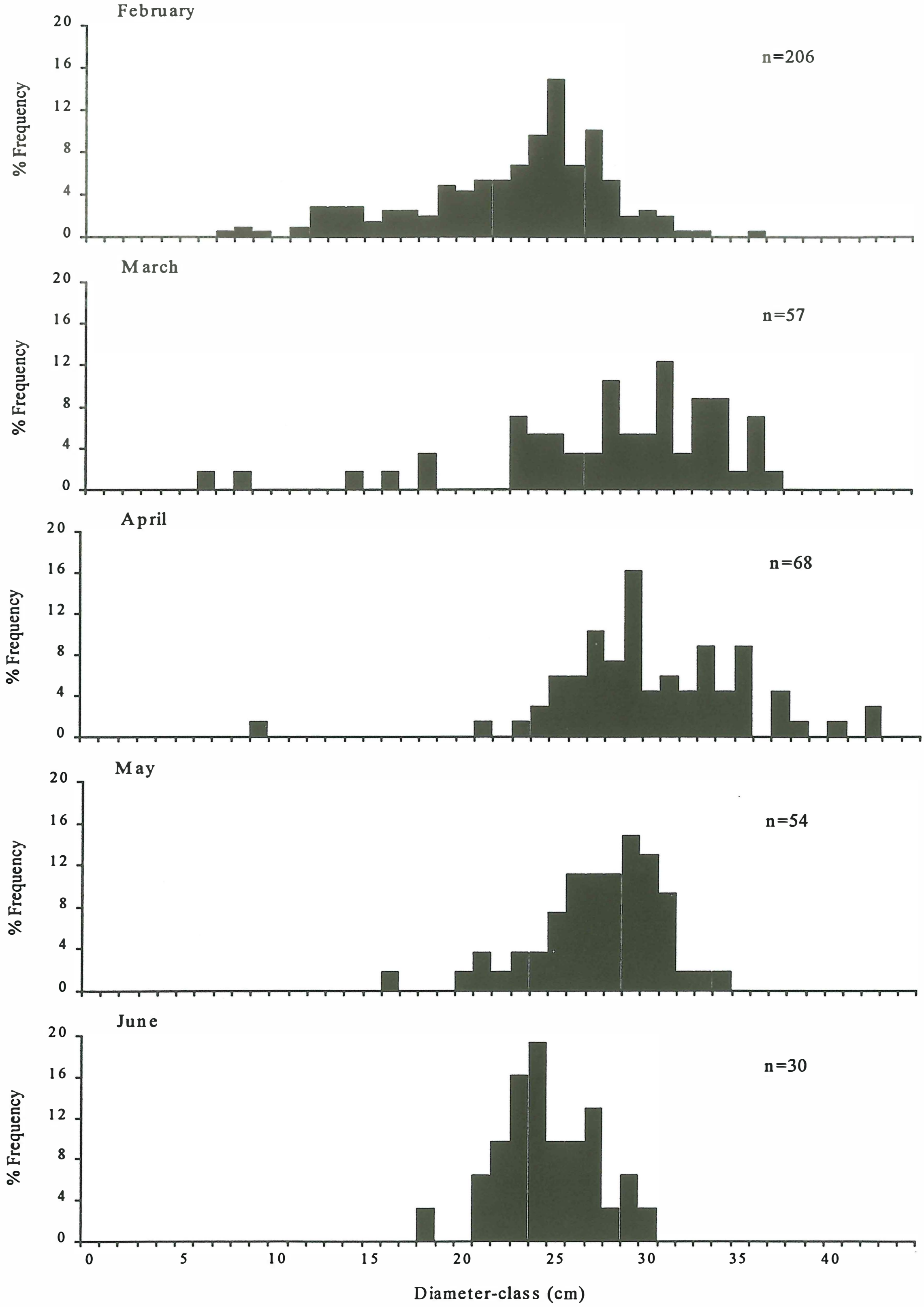


Figure 3. Diameter–frequency of *Catostylus mosaicus* in Port Phillip Bay during 1997.

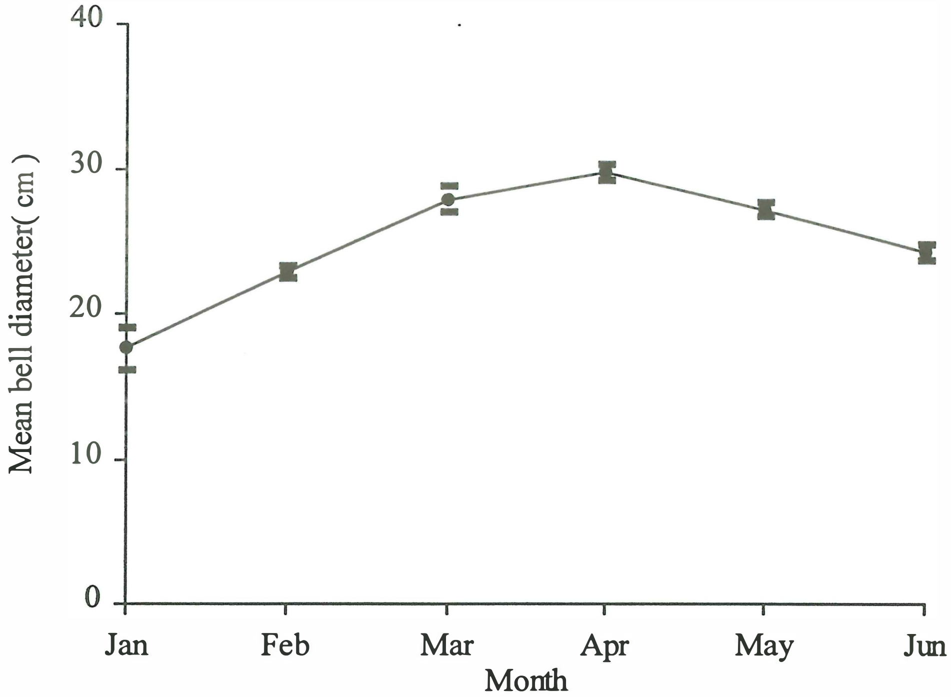


Figure 4. Mean bell diameter (± s.e.) of *Catostylus mosaicus* captured from Port Phillip Bay during January–June 1997.

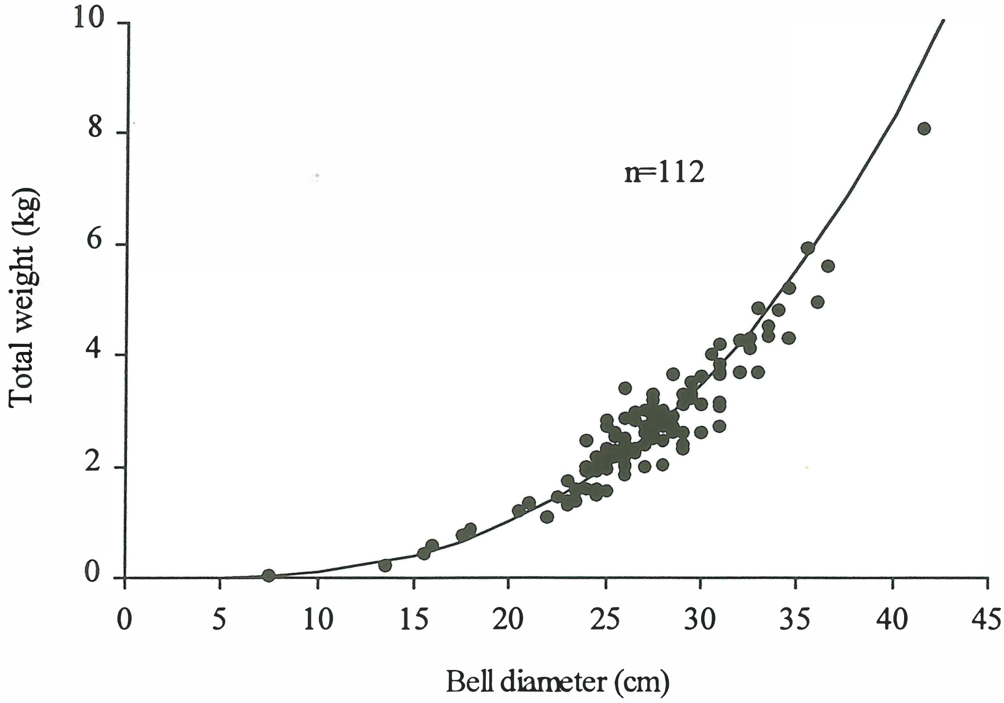


Figure 5. Relationship of total weight–bell diameter (—) for *Catostylus mosaicus* is given by $tw = 1.01\text{x}10^{-4} \text{ x } d^{3.07}$ (r^2=0.94) where *tw* is total weight and *d* is diameter of bell.

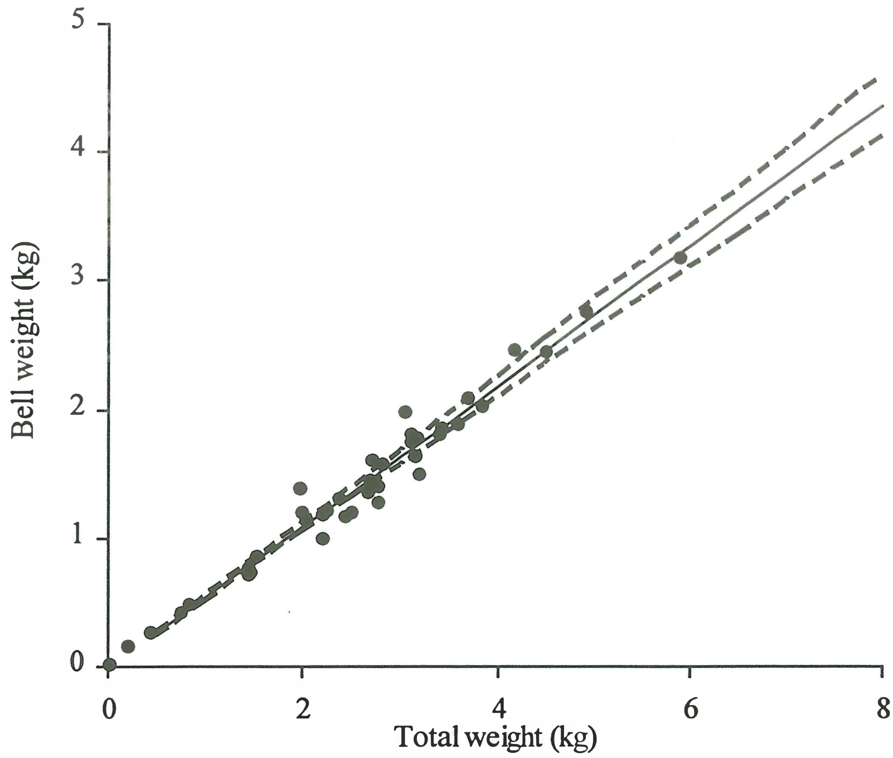


Figure 6. Relationship of bell weight–total weight (—) for *Catostylus mosaicus* with 95% confidence limits (-----) is given by $bw = 0.542tw$ and $r^2 = 0.969$ where bw is bell weight (kg) and tw is total weight.

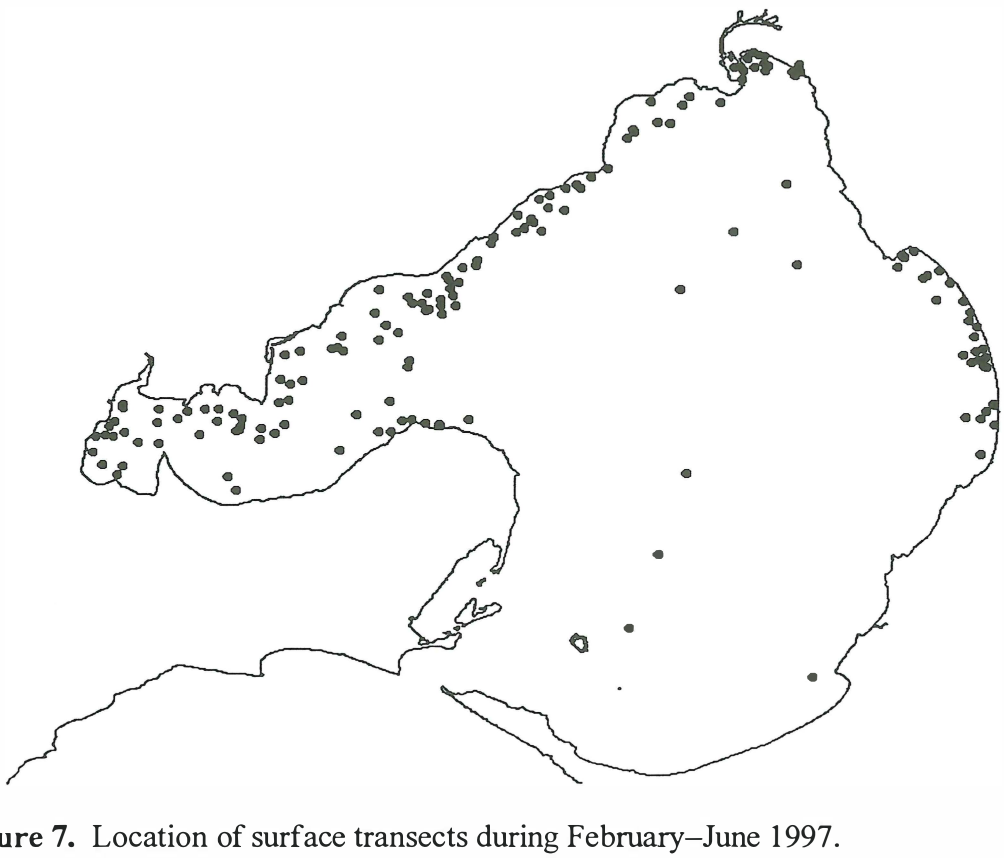


Figure 7. Location of surface transects during February–June 1997.

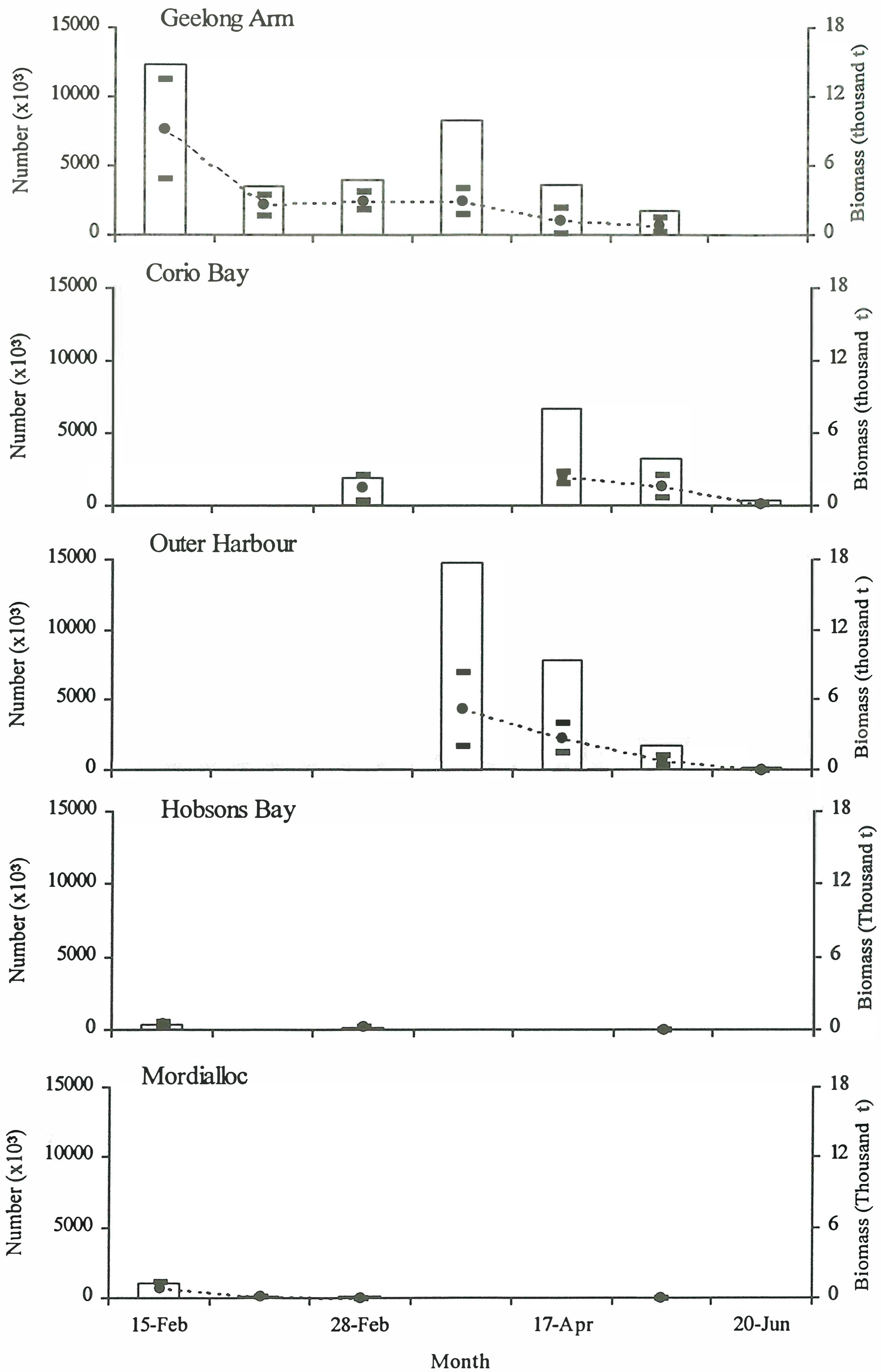


Figure 8. Estimate of the visible numbers of *Catostylus mosaicus* (--●---) with standard errors (-) and biomass (tonnes) (box chart) for cruises conducted on the 15, 19 and 28 February, 11 April, 17 April, 12/16 May and 20 June 1997.

Appendix I: Anecdotal Reports

Numerous reports of jellyfish in Port Phillip Bay were provided by commercial fishers, swimmers and Victorian Fisheries Officers. Historical reports were received of large aggregations of jellyfish in Geelong Arm and Hobsons Bay and reports of smaller aggregations near Beaumaris and Mornington were provided. Fishers commented the species usually appear during late summer and autumn. A large number of *Catostylus mosaicus* were caught by trawl in Corio Bay during March 1995 as part of a MAFRI demersal fish survey. In late March 1996, large numbers of *C. mosaicus* were sighted off Kerford Street Pier during the day and night under calm conditions. The pier was inspected three days later with a 15 knot southerly blowing and no jellyfish observed. They were visible when the seas were calm or slight but not visible when the seas were moderate or rough. Sightings of *C. mosaicus* and *P. haeckeli* tapered off by July 1996 and were then replaced by sightings of small *Cyanea capillata. Cyanea capillata* were frequently observed from shore and offshore from July 1996 to December 1996 over which period the diameters of the medusae increased from about 2 cm to 15 cm. In January and February 1997 we received numerous reports from MAFRI staff and the public of large swarms of *C. mosaicus* in the Portarlington, Werribee River Hobsons Bay, Mentone and Patterson River. There were sightings of large numbers of mature *C. capillata* in the southern part of the Bay but no *C. mosaicus.*

Outside Port Phillip Bay, jellyfish were also sighted on a number of occasions. Large aggregations of *C. mosaicus* were reported from inlets in the northern region of Westernport during April 1996 and off Hastings during February–March 1997. *Catostylus mosaicus* was reported from Corner Inlet during the summer months of 1996 and 1997, but their size was reported as being smaller than those reported in Port Phillip Bay. *Catostylus mosaicus* and *C. capillata* were observed in the Gippsland Lakes where it has been suggested that *C. mosaicus* might have declined because of the increasing frequency of algal blooms during recent years. Also observations of large aggregations of jellyfish were reported offshore from Lakes Entrance but the species were not identified. *A. aurita* was frequently sighted in Lake Tyers during recent years while *C. mosaicus* was absent.

Appendix II: Survey Technique Trials

Underwater Camera Trials

An underwater camera towed by *R.V. Gratis* was trialed to determine whether or not the pattern of vertical distribution of jellyfish in the water column could be observed. These trials were undertaken on 2 May 1996 under conditions of clear sky and light wind in water of 8 m depth 500 m off the pier at Frankston. A Panasonic colour video camera with a 16-mm lens attached to a tow-body was lowered to the sea bed, lifted 2 m, and towed for 10 min at 3 knots. After 10 min of viewing, the camera was brought to within 2 m of the surface and towed for 5 min at 3 knots. A 10-inch video monitor recording position, water depth and vessel speed was mounted on the deck. While the camera was operated a person stood at the bow of the vessel counting jellyfish that could be observed at the surface.

The underwater camera trial was conducted during fine weather and calm conditions. The underwater camera when tested was found to be unsuccessful for counting jellyfish below the surface of the water at sea bed level and near the surface. The field of view was too narrow and objects beyond about 50 cm were indistinguishable. While the camera was being towed significant amounts were easily observed at the surface to a depth ranging 2–3 m.

Aerial Survey

On the 12 February 1997, a single engine Cessna aircraft was flown around the perimeter of Port Phillip Bay to determine if *C. mosaicus* and its distribution could be identified and mapped from the air, and an estimate made on the approximate number per measure of area. The plane was flown in a clockwise direction, at 300 m altitude and speed of 90 knots in the afternoon between 1330 and 1500 hours EST. Conditions were clear with a south-south-easterly wind of 10 knots that increased to 15 knots towards the end of the flight. Large aggregations of *C. mosaicus* in Hobsons Bay and Beaumaris were identified by MAFRI staff immediately before the survey. From the aircraft an observer attempted to identify aggregations of *C. mosaicus* and then mark on a map the approximate boundaries defining the distribution of *C. mosaicus.*

From the aircraft, *C. mosaicus* were only observed in clear shallow water (Figure II 1). MAFRI staff reported large aggregations in Hobsons Bay and Beaumaris, which the observer from the plane did not identify. The waters in Hobsons Bay are often turbid due to the outflow from the Yarra-Maribyrnong River system. The jellyfish observed by MAFRI staff in the Beaumaris area were observed to be well below the surface, and although the water, was clear, *C. mosaicus* was not identified from the air.

As *C. mosaicus* cannot be distinguished in murky waters and an observer aboard an aircraft cannot distinguish jellyfish beloe the surface, aerial surveying was abandoned as a potential method for estimating abundance of jellyfish.

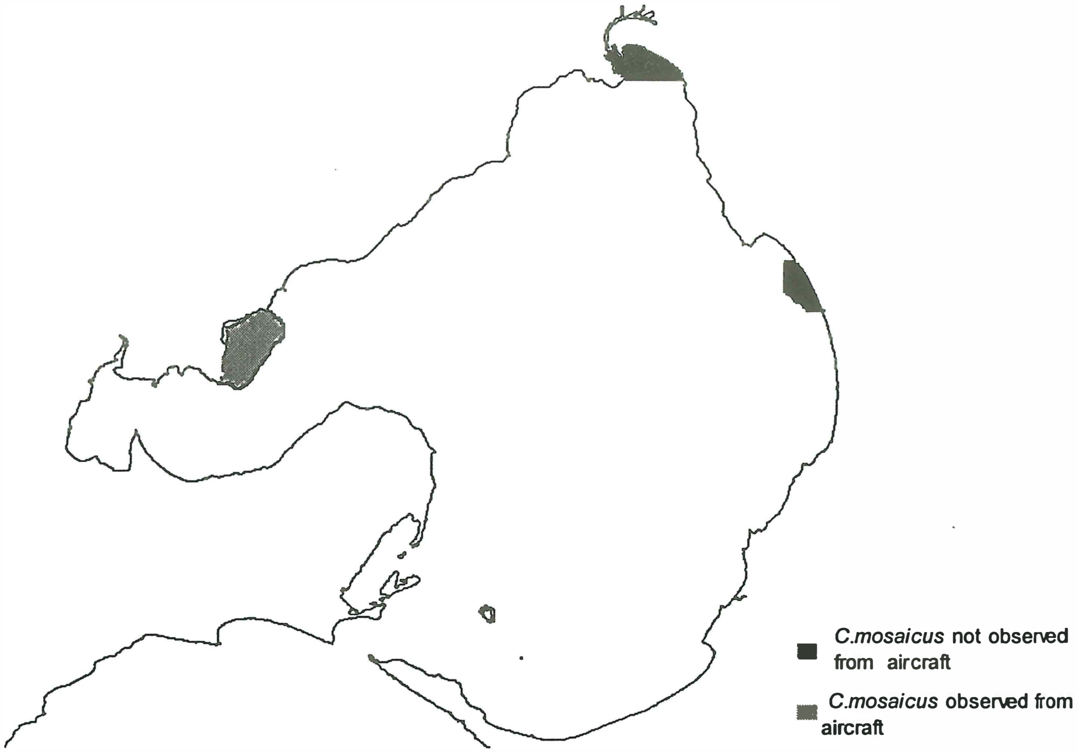


Figure II 1. Areas of known aggregations of *Catostylus mosaicus* observed by aircraft or MAFRI research vessels.

Bongo Net Sampling

A Bongo net was towed during abundance cruises conducted during February 1997 and during May 1997. The Bongo net had a diameter of 97 cm, with a 25 mm nylon mesh net webbing attached. A General Oceanics flowmeter was fitted to the opening. The Bongo net was towed along a transect at the surface for 5 min, while a regular transect was performed. The Bongo net was then emptied, the jellyfish identified and counted, and the flowmeter count recorded. The Bongo net was then lowered to within a metre of the sea bed and towed for a further 5 min before being emptied, and the jellyfish identified and counted. The Bongo net was not deployed in waters less than 3.0 m in depth.

Results from the Bongo net sampling are presented in Table II 1 below. A relationship could not be established between the density of jellyfish observed from the surface tows and the density of jellyfish observed from the bottom tows. On some occasions, the catch of jellyfish in the Bongo net was not representative of the surrounding density of jellyfish. Steaming through dense patch of jellyfish resulted in few or no jellyfish being caught in the net. It was suspected the jellyfish in the surface waters were moving further down the water column when coming into contact with the pressure wakes from the vessel. There also appeared to be a large temporal variation in the vertical distribution of the jellyfish. At certain times they were observed on the sea bed, other times mid-water or on the surface. No jellyfish were caught in Bongo net surveys of the sea bed conducted during May.

The estimates of animals per 100 m^3 in the Bongo net samples were always significantly less than the visible density of jellyfish (per 100 m^3) observed from the vessel.

Table II 1. Comparison of estimates of jellyfish densities between surface transects and surface and bottom bongo net transects during February–May 1997

Cruise	Date	Stratum	No. of transects	Mean no per $100m^3 \pm$ se		
				Surface transects	Bongo net surface	Bongo net bottom
2	14 Feb	Mordialloc	6	3.02 ± 2.49	0.55 ± 0.39	1.41 ± 0.87
3	15 Feb	Hobsons Bay	9	2.59 ± 1.30	1.49 ± 1.09	0.75 ± 0.34
3b	15 Feb	Geelong Arm	3	3.03 ± 1.50	0.30 ± 0.22	1.34 ± 0.66
4	18 Feb	Geelong Arm	5	1.13 ± 0.45	0.14 ± 0.09	0.35 ± 0.24
10	17 Apr	Corio Bay	3	5.19± 2.01	nd	1.07± 0.42
11	12 May	Mordialloc / Hobsons Bay	16	0.06± 0.02	nd	0
12	16 May	Corio Bay	5	2.49± 1.50	nd	0

Appendix III: Preliminary Surveys

Preliminary Survey 1

The first preliminary survey was undertaken at 40 predetermined sites (depth ranging 6–22) as part of a demersal trawl survey conducted by MAFRI during March 1996. The survey was conducted during the day between 0700 hours and 1700 hours EST. In the field, each predetermined site was located by a Geographical Positioning System (GPS). At each predetermined site, a trawl net was lowered to the sea bed and the vessel proceeded in a constant direction for 5 min at 3 knots. During the duration of this trawl, an observer stood at the bow of the vessel counting the number of jellyfish passing within 5 m either side of the vessel. At the completion of the trawl, the trawl net was hauled aboard and the number of jellyfish caught in the net recorded.

During the 4-day period of the survey, the weather conditions ranged from clear sky with no wind to overcast with light to moderate southerly winds. The highest number of *Catostylus mosaicus* observed was in the Mentone area, when weather conditions were calm. Few *C. mosaicus* were observed in the Geelong Arm when conditions at the time were overcast and a 15 knot southerly blowing. Only one *C. mosaicus* was observed in the central part of the Bay (Figure III 1).

Preliminary Survey 2

The second preliminary survey involved a circuit of Port Phillip Bay each month on a predetermined day, by a MAFRI research vessel from March 1996 to January 1997. The survey was consistently undertaken during 0800 and 1500 hours Eastern Standard Time (EST). The vessel stopped at the same stations around the Bay and noted the presence or absence of either *C. mosaicus* or *P. haeckeli* within a 10 m radius around the vessel. The wind speed and wind direction were also noted. These predetermined sites were allotted into four regions, North-east, South-east, Geelong Arm and South-west (Figure III 2).

The survey indicated the presence of both *C. mosaicus* and *P. haeckeli* in the Bay during March, though not in April when the survey was conducted in rough conditions (Table III 1). During July only *P. haeckeli* were observed. Large aggregations of *C. mosaicus* were observed in the Geelong Arm, and the north-east regions of the Bay during January 1997. A general observation from this survey was *C. mosaicus* appeared more abundant at the surface under calm conditions.

Table III 1. Results of second preliminary survey, showing number of medusae *Catostylus mosaicus* and *Pseudorhiza haeckeli* medusae observed in each region of Port Phillip Bay (see Figure 2) during March 1996–January 1997.

CM *Catostylus mosaicus* present; PH *Pseudorhiza haeckeli* present; nd, no data

Month	Geelong Arm	North-east	South-east	South-west
March	CM	CM	CM/PH	PH
April				
May				
June	nd	nd	nd	nd
July	PH	PH	PH	PH
August				
September				
October				
November				
December				
January 1997	CM	CM		
Wind speed (knots)				
March	15	15	15	15
April	20	20	20	20
May	15	15	15	15
June	nd	nd	nd	nd
July	20	20	20	20
August	20	20	20	20
September	20	20	20	20
October	10	10	10	10
November	25	25	25	25
December	15	15	15	15
January	15	15	15	15
Wind direction				
March	NE	NE	NE	NE
April	SW	SW	SW	SW
May	SW	SW	SW	SW
June	nd	nd	nd	nd
July	SW	SW	SW	SW
August	SW	SW	SW	SW
September	SW	SW	SW	SW
October	SE	SE	SE	SE
November	SW	SW	SW	SW
December	SE	SE	SE	SE
January	SE	SE	SE	SE

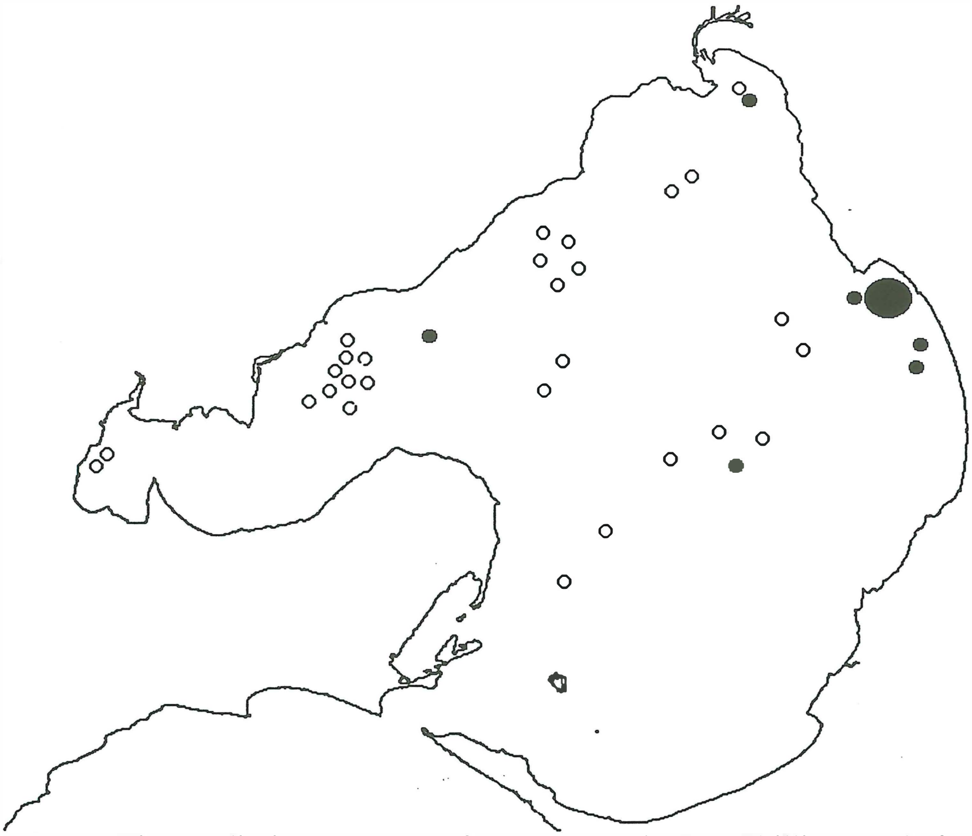


Figure III 1. First preliminary survey of *C. mosaicus* in Port Phillip Bay during March 1996. O denotes no *C. mosaicus* observed, ● denotes 1-5 jellyfish observed, ● denotes 6-10 jellyfish observed, ● denotes 11-15 jellyfish observed.

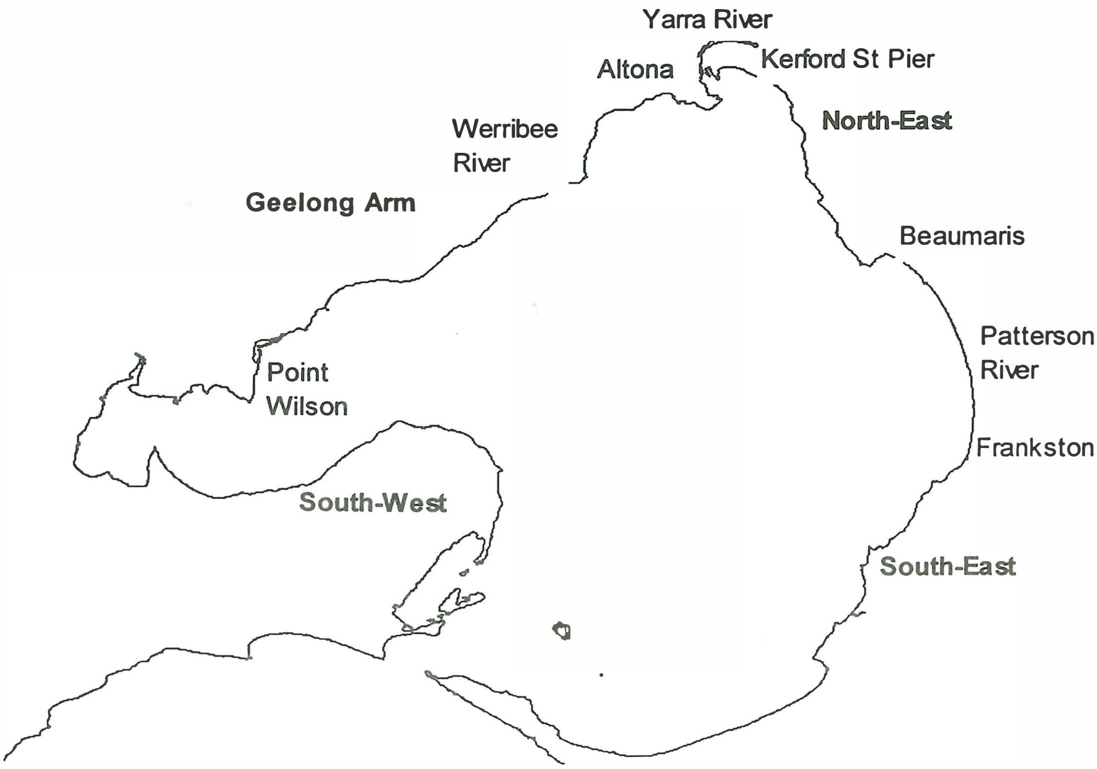
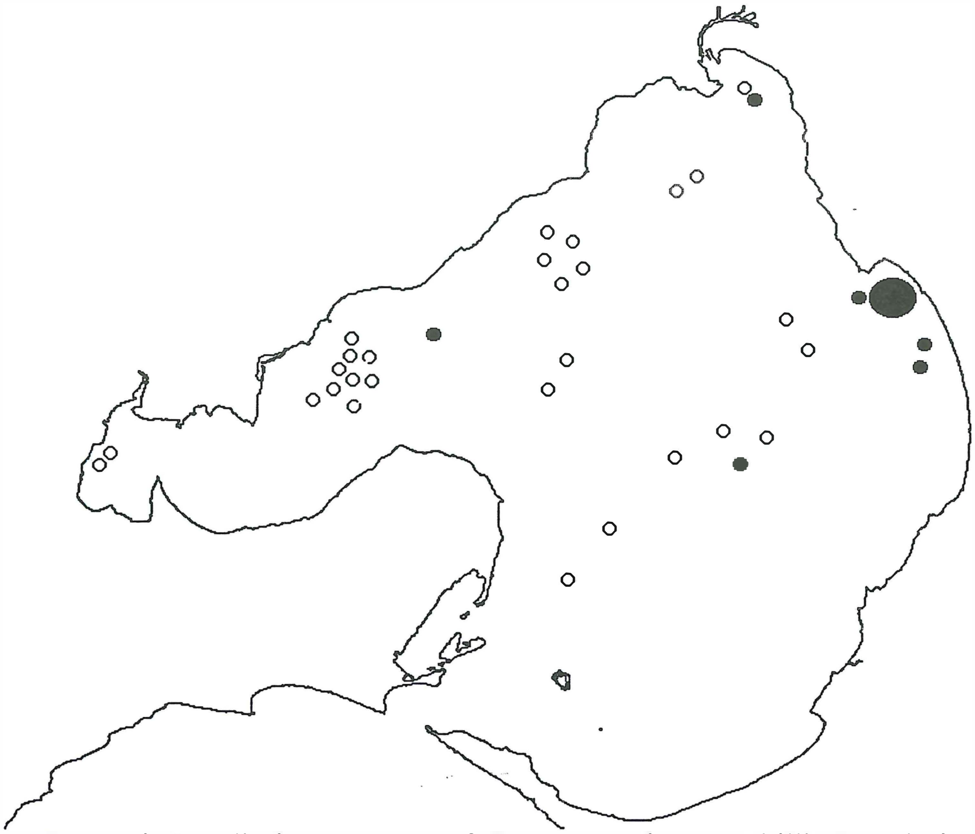


Figure III 2. Regions and localities in Port Phillip Bay designated from second preliminary surveys.



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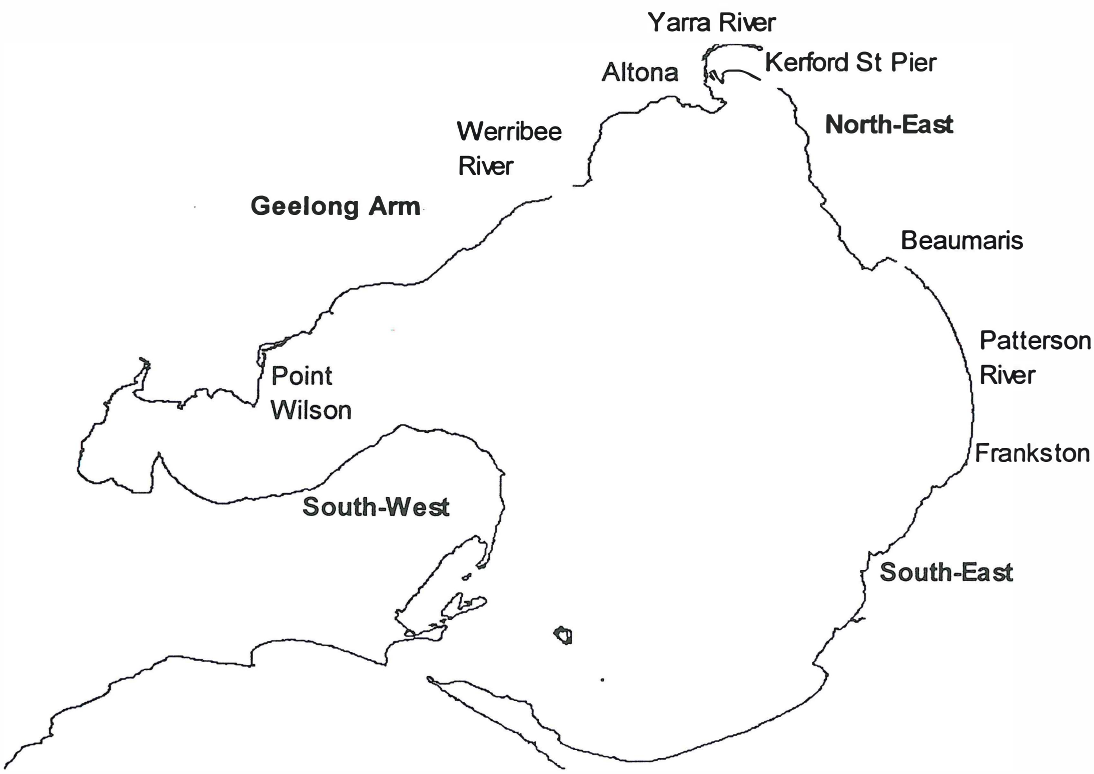

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