STUDIES ON NEW ZEALAND BIVALVE LARVAE,
WITH OBSERVATIONS ON THE ADULTS
AND ON THE HYDROLOGY
OF BAY OF ISLANDS AND WELLINGTON HARBOUR.

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ABSTRACTS

- (1) Observations made on some hydrological parameters at Bay of Islands and Wellington Harbour during 1970-71 are presented and discussed. The parameters include water temperature, salinity, dissolved oxygen content and turbidity. The water current system in Bay of Islands is also discussed and a proposed pattern presented.

The hydrology of Bay of Islands and Wellington Harbour are compared. Bay of Islands is topographically less isolated from oceanic influence than Wellington Harbour, and there is a more marked change from estuarine to oceanic hydrological conditions within the bay.

Monthly mean surface seawater temperatures at Bay of Islands exceed those of Wellington Harbour by about 4 degrees C. Water temperature stratification is more marked in Bay of Islands than Wellington Harbour, suggesting less efficient water mixing. Salinities are lower in Wellington harbour (normally about 33.5 - 34.5 parts per thousand) than the main basin of Bay of Islands (normally about 35.5. parts per thousand). Turbidities in estuarine areas of Bay of Islands are similar to those for most of Wellington Harbour (3 - 6 metres Secchi Disc visibility values), but are much less in outer basin areas (Secchi Disc visibility values may exceed 15 metres). Dissolved oxygen content is high in both harbours, frequently exceeding 100 per cent saturation in surface water.

The results suggest that although both harbours are hydrologically quite homogeneous, Wellington Harbour is more efficiently mixed than Bay of Islands.

- (2) Benthic and shore collections of marine bivalve molluscs were made in Bay of Islands, and benthic collections were made in Wellington Harbour, during 1970-72. The species occurring are recorded and discussed, and the distribution of some common species in Wellington

Harbour is related to sediment types.

A list of bivalve molluscs collected in Bay of Islands is presented, and additional species to previous Wellington Harbour species lists are recorded.

Invertebrate marine communities described for New Zealand are discussed, and the bivalve fauna of both harbours is visually compared to these communities. The observations at fiftyfour anchor dredge benthic stations in Wellington Harbour are then treated statistically, and compared to the visual assessments. It appears that the great variability in Wellington Harbour sediments makes identity of classical communities in the harbour almost impossible. However, station groups (groups of stations with similar bivalve species present) are evident, and their distribution in Wellington Harbour correlate closely to sediment type distribution.

Lists of the most abundant bivalve species occurring in both harbours, deduced from all the observations presented in this study, are given.

- (3) Observations were made on the occurrence of common late stage bivalve larvae in the plankton at Bay of Islands and Wellington Harbour during 1970 - 71. Three stations in Bay of Islands and four stations in Wellington Harbour were sampled approximately monthly.

The bivalve larvae in shorter series of plankton samples from Raumati Beach, Dargaville Beach, Mahurangi, Ohiwa Harbour, Raglan Harbour and Kaipara Harbour during 1971 - 72 were also analysed.

Twenty-nine species of bivalve larvae from these plankton samples are described. Twenty-three species of late stage bivalve larvae are provisionally identified, the identifications being based on the larval hinge structure, the distribution and abundance of the larvae in relation to adult stocks, and in some cases by correlation

with the adult gonad or condition index cycle.

The broad seasonal pattern of occurrence of twentyfive species of late stage bivalve larvae in the plankton at Bay of Islands, Wellington Harbour and Raumati Beach is presented.

- (4) Ecological studies made on bivalve larvae at Bay of Islands and Wellington Harbour during 1970 - 71, are presented and compared to other published studies from overseas.

Included are observations on the vertical meso-distribution of bivalve larvae over tidal cycles in estuarine and non-estuarine localities of 12m to 15m depth, the daytime vertical meso-distribution of bivalve larvae in non-estuarine water 20m - 30m in depth, the effect of light on the vertical meso-distribution of bivalve larvae in water 15m - 30m in depth, and the horizontal mega-distribution of bivalve larvae in Wellington Harbour and Bay of Islands.

The observations suggest that in estuarine areas, the effect of alternating tides on the vertical distribution of bivalve larvae far outweighs the effects of any other factors. During the flood tide, bivalve larvae rise from the bottom into the water column and are carried up the estuary by the tide. During the ebb tide the larvae settle and remain on the bottom.

In non-estuarine areas, no such vertical migration was observed. Gravity, light and water currents, in particular, affect the vertical distribution of bivalve larvae in these areas.

The horizontal mega-distribution of bivalve larvae within Wellington Harbour is fairly uniform. In Bay of Islands, bivalve larvae occur in greatest densities near the shores, while much of the central basin is almost devoid of larvae. This distribution is due to the proximity of the adult stocks to the regions of most larvae, and to the prevailing water current pattern within the bay.

GENERAL INTRODUCTION

This study was initially prompted by the lack of knowledge about New Zealand bivalve larvae and their development. The identification of bivalve larvae assists the accurate prediction of spatfalls, and the determination of spawning periods of bivalve molluscs, several of which provide the basis for an important fishery in this country. The natural stocks of the shellfish can last only a limited time before careful management of larval resources becomes necessary.

The bivalve larvae of two areas in New Zealand (Bay of Islands and Wellington Harbour) were regularly sampled to ascertain the most abundant late stage larval species present, and to determine the broad seasonal occurrence of some of these species. Plankton samples were taken approximately monthly over an eighteen month period at both harbours. Simultaneous hydrological observations were also made, and these, with a description of the two harbours, are presented and discussed in the first section of the thesis.

The quite recent development overseas of techniques for the laboratory rearing of bivalve larvae made it seem likely that several of the New Zealand species could be reared in the laboratory, and be described and positively identified.

However, the very small amount of success in the laboratory-rearing work made it necessary to use less direct methods to identify the bivalve larval species which were occurring in the plankton samples. These indirect methods required a fairly thorough knowledge of the adult bivalve fauna present in both the harbours.

At the time this work was being done the opportunity arose to make a more detailed analysis of the Wellington Harbour bivalve fauna with regard to the presence of classical communities. The results of the faunal studies are given in Section 2 of the thesis.

The most abundant bivalve larvae encountered in the plankton samples are described and provisionally identified in the third section

of the thesis, and comments included on the broad seasonal spawning cycles of some of the species.

The last section deals with observations made on the ecology of the bivalve larvae at the two harbours, and in particular comments on aspects of the vertical distribution of the larvae.

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SECTION 1

OBSERVATIONS
ON THE
HYDROLOGY
OF
BAY OF ISLANDS
AND
WELLINGTON HARBOUR,
NEW ZEALAND
FOR 1970-1971

SUMMARY

Observations made on some hydrological parameters at Bay of Islands and Wellington Harbour during 1970-1971 are presented and discussed. The parameters include water temperature, salinity, dissolved oxygen content and turbidity. The water current system in Bay of Islands is also discussed and a proposed pattern presented.

The hydrology of Bay of Islands and Wellington Harbour are compared. Bay of Islands is topographically less isolated from oceanic influence than Wellington Harbour, and there is a more marked change from estuarine to oceanic hydrological conditions within the bay.

Monthly mean surface seawater temperatures at Bay of Islands exceed those of Wellington Harbour by about 4 degrees C. Water temperature stratification is more marked in Bay of Islands than Wellington Harbour, suggesting less efficient water mixing. Salinities are lower in Wellington Harbour (normally about 33.5 - 34.5 parts per thousand) than the main basin of Bay of Islands (normally about 35.5 parts per thousand). Turbidities in estuarine areas of Bay of Islands are similar to those for most of Wellington Harbour (3 - 6 metres Secchi Disc visibility values), but are much less in outer basin areas (Secchi Disc visibility values may exceed 15 metres). Dissolved oxygen content is high in both harbours, frequently exceeding 100 per cent saturation in surface water.

The results suggest that although both harbours are hydrologically quite homogeneous, Wellington Harbour is more efficiently mixed than Bay of Islands.

INTRODUCTION

Bay of Islands is a large open harbour on the east coast of Northland with estuarine to oceanic hydrological conditions. Wellington harbour is a smaller, more enclosed harbour at the south end of the North Island. (Fig.1.1)

Studies were made on the bivalve larvae of the two harbours during 1970-1971, and associated hydrological observations are analysed here.

PREVIOUS WORK.

General accounts and summaries of the oceanography and hydrology of the New Zealand region include those of Hefford (1947), Garner (1959, 1961 and 1962), and Garner and Ridgway (1965). There are no specific accounts of the hydrology of the north east coast of New Zealand, although Stanton (1969), Ridgway and Stanton (1969), and Barker and Kibblewhite (1965) gave hydrological accounts of the northern half of New Zealand. The hydrology of Wellington harbour was described by Gilmour (1960 b), and Maxwell (1956).

Current patterns in the New Zealand region were summarised by Garner (1954, 1959), Bary (1959), and Brodie (1960). There are no accounts of the currents in Bay of Islands; Brodie (1958) described the circulation in Wellington Harbour, and Heath (1969 and 1971), Gilmour (1960 a) and Olsson (1955) described currents in neighbouring Cook Strait.

The general hydrological accounts mentioned included observations on temperature and salinities of the northeastern and central New Zealand region. Skerman (1958) summarised accounts of annual surface temperature variations in some New Zealand harbours up to 1958, and included diurnal temperature observations in Wellington Harbour. Other temperature data for Wellington Harbour include that given by Garner (1953), Brodie (1958), Hurley (1959), Wear (1965), Ritchie (1970), and Heath (1971). Temperature observations for Bay of Islands were given by Hounsell (1935) and Hefford (1947).

Other salinity data for the northeastern New Zealand region were given by Fuller (1953), with observations from Hauraki Gulf to Cape Brett; for the Wellington region, Garner (1953), Johannesson (1955), Brodie (1958) and Heath (1971).

There is no data on any other hydrological parameters from Bay of Islands; Maxwell (1956) included pH measurements from Wellington harbour.

STATIONS

Observations were made approximately monthly at the hydrological/plankton stations shown in Figures 1.3 for Bay of Islands, and 1.16 for Wellington harbour, from May 1970 to January 1972, although there are occasional observations from other stations in these harbours, which will be described later. Table 1.1 gives the position and depths of the stations.

TABLE 1.1 HYDROLOGICAL/PLANKTON STATIONS

	<u>Station</u>	<u>Longitude E</u>	<u>Latitude S</u>	<u>Depth(m)</u>
<u>Bay of Islands</u>	Confluence	174° 3.5'	35° 11.8'	15
	Brampton Reef	174° 5.2'	35° 14.0'	18
	Waewaetoria	174° 12.4'	35° 12.6'	16
<u>Wellington Harbour</u>	Mahanga Bay	174° 50.1'	47° 17.7'	14
	S.W.Somes Island	174° 51.5'	47° 16.0'	22
	Petone Beach	174° 52.3'	47° 14.0'	5
	Ngauranga	174° 49.0'	47° 15.0'	18

METHODS

COLLECTION OF HYDROLOGICAL DATA.

In Bay of Islands a 19 foot outboard launch was used, although from May 1971 a fishing boat was hired to sample outer stations. Day cruises on M.V. "Ikaterere" (60 ft.) were made in February and September 1971.

In Wellington Harbour, observations were made from M.V. "Tirohia" (43 feet) of the Zoology Department, Victoria University of Wellington, and from a 14 foot open outboard whaler.

1. Temperature data was collected in five ways:

- (a) subsurface temperatures at approximately 15 cm. depth, or from a bucket of surface water, read with mercury thermometers with accuracies better than $\pm 0.3^{\circ}$ C.
- (b) Beckman RH5 salinometer. This instrument was tested and calibrated by the Physics Department, Victoria University, to be within the $\pm 0.5^{\circ}$ C limit given by the instruction manual.
- (c) Petersen water bottle equipped with thermometer ($\pm 0.2^{\circ}$ C)
- (d) MK1S 575 bathythermograph (and occasionally a MK1 612 in deeper waters) from M.V. "Ikateri" in Bay of Islands. The instrument was calibrated for each drop by measuring the sea surface temperature with two mercury thermometers ($\pm 0.05^{\circ}$ C).
- (e) Murayama Electronic Resistance Thermorecorder (MK 2) on M.V. "Tirohia", with tested accuracy of $\pm 0.5\%$ (Bartle, 1972).

The method of temperature observation is given with each set of results.

2. Salinity data was collected in three ways:

- (a) surface and subsurface (Petersen water bottle) samples were stored in sealed 250 ml. reagent bottles until determined in the laboratory with a Beckman RS7B Salinometer, calibrated against standard sea water.
- (b) larger volumes were analysed within two hours by a zeal hydrometer, with an accuracy better than ± 0.2 ‰.

(c) Beckman RH5 Salinometer, calibrated by the Physics Department, Victoria University, to be within the $\pm 0.3^{900}$ limits given in the instruction manual.

The method of determination is given with each set of results.

3. Dissolved oxygen was determined by the Winkler titration (Strickland and Parsons, 1968). Samples were obtained from all depths by a Petersen water bottle, carefully piped into 250 ml. reagent bottles without splashing or bubbling, the Mn sulphate and KI solutions added immediately, the bottles sealed, and later the precipitated manganous-manganic hydroxide dissolved and titrated in the laboratory. Rochford (1951) gives the routine precision of the Winkler titration to be approximately ± 0.025 ml. oxygen/l. percent oxygen saturation, which relates the observed values for oxygen concentration (in ml/l), and the amount which could be dissolved at the temperature of the observation, was determined by the Miyake method (Ramsey, 1960):

$$\text{Per cent saturation} = \frac{O_a}{O_b} \times 100$$

where O_a = measured oxygen content of the water

O_b = solubility of oxygen in the water at the observed temperature and salinity when in equilibrium with a standard atmosphere having a total pressure of 760 mm.

Since hydrostatic pressure must be taken into account when samples are taken from a given depth, the solubility of a gas cannot be considered to be the same as the value when in equilibrium with normal atmospheric pressure. Miyake's method considers this:

$$S_a = \frac{O_a}{O_b \times P/760} \times 100$$

S_a = per cent saturation

O_a = observed concentration of oxygen in ml/l

O_b = solubility of oxygen from the air (in ml/l) at observed temperature and standard pressure for depth of sample (in mm)

Ob values were obtained from Table 2 of Truesdale and Gameson (1956).

4. Water turbidities were measured with a plain white 30 cm. diameter Secchi Disc. Sea and sky conditions were usually recorded at the same time.

5. Current velocities. No current meter was available. Data was collected using a TSK flow meter mounted on metal vanes which oriented it into the prevailing current. It was lowered and raised vertically, and left for a constant period at the required depth. The estimated additional revolutions of the propeller due to the raising and lowering were subtracted from the total number of revolutions acquired. The instrument was intended to give relative not absolute current velocity values.

6. Current systems. Two hundred and fifty plastic covered drift cards (Ols on, 1951) were released at four stations in Bay of Islands during 1970-1971, and two hundred and fifty cards were released at five stations outside Bay of Islands in February and March 1972, and probable transit paths plotted to their points of recovery.

Five drift drogues were released during 1971, and the transit paths plotted for the two recovered. The parachute was set at 8m, hence the drogue responded to currents at that depth.

BAY OF ISLANDS

(A). PHYSIOGRAPHY AND GENERAL HYDROLOGY. (Figs 1.2, 1.3 and 1.4)

Bay of Islands is an embayment of about fifty square miles containing several large estuaries and approximately two hundred islands. Only the larger islands are shown in Figs 1.2 and 1.3. Tidal waters extend inland as far as Kerikeri and Kawakawa.

Within the bay the depth of water is up to thirty-five fathoms, but reaches fortyfive fathoms at the seaward limit (Fig.1.2).

Much of the terrain surrounding outer areas of the bay is steep and gullied, and provides little effective rainfall catchment area. But inner areas are more moderately rolling and provide more effective rainfall catchment. The main freshwater inflows are the Kerikeri, Waitangi, Kawakawa and Waikare Rivers, (Fig 1.3).

Finkelstein (1961) estimates the annual open water evaporation at Kaitaia (50 miles north west of Bay of Islands) to be 86 cm. (cf. Lake Grassmere 112 cm, highest in New Zealand); the evaporation is probably higher for Bay of Islands because of its greater exposure to wind.

The shoreline varies from fine mud in estuarine localities to sandy beaches in more open areas, and to pebble beaches in the exposed regions. Fig 1.4 shows the distribution of the main types of shore. Most of the muddy shoreline lies within the estuaries, and is exposed at low tide with mangroves and saltmarsh grasses occurring widely in the supralittoral zone. At low tide the water becomes restricted to narrow channels of about 20% of the high tide water surface area.

Much of the coast was once bush-covered but grass and scrub now predominate.

On the east coast of Northland, the tidal stream floods northwards, turning west into the bay at Cape Brett, and the sequence is reversed on the ebb tide. Tides are semidiurnal, with mean amplitudes of 2.0 and 1.4 metres for HWS and HWN tides (New Zealand Tide Tables, 1972). Greatest current velocities and water mixing occur at the constricted mouths and points of confluence of the estuaries.

The open coastal water is affected by the south-moving East Australian (Auckland) current (Brodie, 1960), but its effect on water movements inside the bay is unknown.

FIG. 1.1 Location map showing
Bay of Islands and Wellington Harbour.

FIG. 1.2 BAY OF ISLANDS
Depth **contours** (fathoms) and inlet system
(from Hydrographic map N.Z. 5122).
The 50 fathom contour is the 94 metre contour,
the 20 fathom countour is the 38 metre contour, and
the 10 fathom contour is the 19 metre contour,
approximately.

FIG. 1.3 BAY OF ISLANDS
Hydrological/plankton stations.
Freshwater inflow and townships.

FIG. 1.4 BAY OF ISLANDS
Distribution of main shore types.

FIG. 1

FIG. 2

FIG. 3

FIG. 4

The near coast open sea water surface temperatures and salinities are very high. The harbour is influenced by freshwater inflow from river discharge and rainfall, but salinities generally exceed $35.5^{\circ}/\text{oo}$.

The area is sparsely populated with 12,790 people in the Bay of Islands Administrative County in 1970, mainly employed in farming (New Zealand Yearbook, 1971). The fertilizers from the topdressing of the soil are frequently washed into inner harbour areas after heavy rain, giving rise to algal blooms.

(B). CLIMATE.

Northland lies in the warm temperate zone of New Zealand and has a wet, mild climate (McLintock, 1960). De Lisle and Kerr (1964) summarise the weather and climate of the region. Extracts from the climatological table for Kerikeri are given in Fig.1.5 (from New Zealand Meteorological Service, 1966).

Kidson (1931b) shows the annual sealevel air temperature of Bay of Islands as being just above the 57°F isotherm, which is the highest in the country. East coast temperatures exceed those on the west coast at the same latitude because of the prevailing westerly winds.

Kidson (1931a) describes the rainfall of Northland as Type A, with the heaviest fall occurring during winter (Fig. 1.5). The rain falls approximately 5% of the time according to Gabites (1960), with approximately one-third of the mean annual fall of 114-178 cm. falling during the three winter months, and only one fifth during the summer months (de Lisle and Kerr, 1964). Seelye (1940) describes the variability of annual rainfall in the Bay of Islands area as being 18-20%, which is the highest in New Zealand. (Percentage variability is defined as the average departure of the annual totals from their mean, expressed as a percentage of the mean). The proximity of the sea and the absence of any large mountain masses makes the relative humidity high in all seasons (de Lisle and Kerr, 1964), often being between 90-100% during clear nights.

The airflow over Northland is predominantly from the southwest, but in summer and autumn the number of days with winds from an easterly quarter is, in many places, about equal to the number of days with winds from the southwest, (de Lisle and Kerr, 1964). Watts (1947) records northeast winds occurring 21% of the time at 0900 hours at Whangarei, which is on the East coast, 40 miles south of Bay of Islands. The whole area, according to de Lisle (1965) who analysed wind speed returns over twenty years, has an 80-89 m.p.h. maximum gust wind speed. Frosts occur

inland occasionally in winter, but seldom on the shore line and probably never intertidally. Kerikeri, Bay of Islands, has an average of 28 days of ground frost per year over a nine year period 1951-60 (New Zealand Meteorological Service, 1966), but this is high compared to much of the rest of Northland.

Sub-tropical depressions may occur at any time of the year, but more frequently develop into major storms in winter. Tropical cyclones and other storms of tropical origin affect Northland once or twice a year between December and April, bringing heavy rain and strong winds (Barnett, 1938, and Coulter, 1965). Bay of Islands has an average of ten to twelve thunderstorms per year (Watts, 1947), and resultant flooding decreases salinities in the estuaries and surface salinities in the harbour basin.

The monthly mean total radiation in langleys per day, according to de Lisle (1966), varies from 550 in December-January to 200 in June-July. The radiation values for the country show a small latitudinal gradient in spring and summer compared to autumn and winter.

Watts (1947) records Bay of Islands having an average of 2100 - 2200 hours of sunshine per year, and the area receives approximately 50% of the possible sunshine according to Gabites (1960).

(C) CLIMATOLOGICAL OBSERVATIONS FOR 1970-1971.

Observations made daily at 0900 hours at the Waitangi Meteorological Station are given in Fig.1.6. Waitangi is closer to the coast than Kerikeri (Fig. 1.3), and has smaller diurnal annual temperature variations, more wind and less rainfall. The air temperature values for Waitangi for 1970-1971 were generally higher than the averaged Kerikeri values in Fig. 1.5.

Table 1.2 shows the relationship between wind measurements made at 0900 and 1300 at Waitangi. The wind most commonly changes in direction between these times, although it is more likely to remain

within the same quarter. Also it generally increases in intensity by 1 to 3 Beaufort numbers between 0900 hours and 1300 hours.

Data for late spring, summer and autumn only are given in Table 1.2. It is assumed that the winter and early spring daily wind changes are similar.

Winds in 1970-71 were predominantly from the east during the summers, and from the west during the winters, and were strongest during the summers.

Rainfall was greatest in the winter months.

The highest air temperatures occurred in February in both years, and the lowest in June or July.

TABLE 1.2. ANALYSIS OF SOME BAY OF ISLANDS WIND DATA.

The table compares 0900 hour wind readings at the Waitangi Meteorological office with those taken at 1300 hours.

Key to columns

- A. Total percentage of days of month in which the wind changes in direction.
- B. Internal percentage of A - days of month in which the wind changes direction by

$< 90^{\circ}$	90°	$> 90^{\circ}$
----------------	--------------	----------------
- C. Total percentage of days of month in which the wind changes in intensity, irrespective of the direction.
- D. Internal percentage of C - days in which the wind increases in intensity.
- E. Total percentage of days of month in which the wind changes only in intensity.
- F. Internal percentage of E - days in which the wind increases in intensity.
- G. Total percentage of days of month in which there is no wind change in either direction or intensity.

TABLE 1.2.

ANALYSIS OF SOME BAY OF ISLANDS WIND DATAFor explanation, see page 13

	<u>Wind changes</u>				<u>Wind changes</u>				<u>No wind</u>
	<u>in direction.</u>				<u>in intensity</u>				<u>changes</u>
	<u>A</u>	<u>B</u>			<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>
1970 March	26	61	27	12	68	86	48	85	26
April	37	49	13	38	68	100	45	100	18
Dec.	52	56	25	19	64	85	22	86	26
1971 Jan.	26	61	27	12	61	84	42	85	32
Feb.	47	53	38	9	61	88	25	86	28
Mar.	59	17	44	39	74	91	22	100	19
* Nov.	50	70	20	10	55	91	30	83	20
Dec.	38	68	16	16	45	100	23	100	39
1972 Jan.	67	49	21	30	77	75	23	57	10
Feb.	34	50	40	10	55	87	31	78	35
Mar.	73	52	16	32	38	83	8	50	19
Mean	46	53	26	21	61	88	29	83	25

* Readings from 10th - 30th November only.

(D) HYDROLOGICAL OBSERVATIONS FOR 1970-711. Temperature.

Surface seawater temperatures were taken regularly at three points in the harbour during 1970-1971, and are given in Table 1.3.

- (1) At Russell, temperatures were taken off the wharf in 5m of water at 10.00 hours.
- (2) At Otehei Bay, temperatures were taken in 2m of water at 13.00 hours.
- (3) At Wairoa Bay, temperatures were taken in 20m of water at 11.30 hours.

In all three places the mercury thermometer was immersed in a bucket of surface seawater, and allowed to reach equilibrium in a shaded position, and read to 0.2°C .

Fig.1.7 compares the mean water temperatures from Table 1.3 with the monthly mean air temperature, and with monthly mean water temperatures of previous records from Bay of Islands.

Monthly surface water temperatures were taken at Confluence and Waewaetoria (Fig.1.3) and are given in Fig.1.8. The surface water temperatures at the more estuarine Confluence station are affected by air temperatures considerably more than the surface water temperatures at Waewaetoria.

Table 1.4 gives the winter surface temperature and salinities (May, 1971) in Bay of Islands; Fig. 1.9 (A and C) the spring values, and Fig.1.10 (B) the mid-summer values.

Surface salinities and temperatures were taken at both Brampton Reef and Confluence over a tidal cycle on 4/2/71. Salinities varied by no more than $0.25^{\circ}/\text{oo}$, and temperatures by less than 0.8°C .

Subsurface seawater temperatures. Temperature profiles for the harbour are given in Fig. 1.10 (C) for February 1971 and Fig.1.11(B) for September 1971.

Subsurface temperatures were taken at Confluence at 1m, 8m and 15m over complete tidal cycles in late winter 1970 and midsummer 1971. They showed no stratification and little variation. The data for the midsummer 1971 tidal cycle are given in Fig. 4.4.

2. Salinity.

Surface salinity data for Bay of Islands are given in Figs. 1.9 (B and C), and 1.10 (A), and Table 1.4.

Other surface and subsurface salinities from the Bay of Islands hydrological stations are given in Tables 1.5 and 1.6.

Surface salinities transects across the harbour were made during the outgoing and incoming tides on 8/2/71. The results are given in Fig. 1.12.

3. Dissolved Oxygen.

Per cent oxygen saturation values observed at 1m, 8m and 15m over part of a tidal cycle in midsummer 1971 at the Confluence showed little stratification or variation. The observations are given in Fig. 4.4.

Table 1.7 gives further dissolved oxygen values for four localities in Bay of Islands.

TABLE 1.3

BAY OF ISLANDS SURFACE SEAWATER TEMPERATURES °C

- 1. Russell Wharf
- 2. Otehei Bay
- 3. Wairoa Bay

Number of Observations (days)				Highest Recording			Lowest Recording			Mean Recording			Overall Mean
1	2	3		1	2	3	1	2	3	1	2	3	
1970	-	2	2	-	15.8	14.2	-	15.5	14.1	-	15.7	14.2	15.0
	-	6	5	-	16.0	16.5	-	14.0	13.8	-	14.9	14.6	14.8
	2	8	7	15.4	16.0	17.5	14.6	14.0	14.8	15.0	15.1	16.1	15.4
	18	7	5	17.0	17.0	17.0	14.0	16.0	16.0	16.0	16.4	15.9	16.1
	9	3	3	17.0	17.0	16.5	14.8	16.3	16.0	16.0	16.8	16.3	16.4
	24	5	2	20.2	20.5	20.0	17.0	18.0	20.0	18.6	18.9	20.0	19.2
	18	1	1	22.0	-	-	18.9	-	-	20.7	20.8	21.5	21.0
	15	4	6	23.8	23.8	23.3	21.4	21.5	21.8	22.5	22.7	22.4	22.5
1971	15	-	-	24.6	-	-	21.6	-	-	23.1	-	-	23.1
	17	-	-	22.5	-	-	20.2	-	-	21.6	-	-	21.6
	19	-	1	20.7	-	-	18.7	-	-	19.6	-	-	20.5
	14	0	9	19.8	-	19.5	16.4	-	17.0	18.4	-	21.3	18.4
	13	3	3	18.0	18.8	17.8	14.9	16.0	16.5	16.6	17.3	17.3	17.1
	13	4	3	16.0	15.5	16.5	13.0	15.0	15.5	14.8	15.2	16.0	15.3
	-	1	-	-	-	-	-	-	-	-	16.5	-	16.5
	-	3	9	-	16.8	16.3	-	16.0	15.0	-	16.3	15.7	16.0
	8	1	9	16.8	-	15.5	15.3	-	14.8	16.3	16.5	15.2	16.0
	19	-	8	19.6	-	20.0	16.5	-	16.5	18.1	-	17.6	17.9
	9	-	3	21.1	-	21.3	17.3	-	18.0	18.6	-	19.4	19.0

FIG. 1.5

BAY OF ISLANDS

Meteorological observations for Kerikeri

(from New Zealand Meteorological Service, 1966).

- A. Mean air temperature with mean monthly maxima and minima (1915-60) in $^{\circ}\text{C}$.
- B. Mean rainfall (1921-60) in inches.
(scale in cm. is 0, 10.2 and 20.4)

FIG. 1.6

BAY OF ISLANDS

Meteorological observations for Waitangi, 1970-72, based on 0900 hours readings.

- A. Rainfall in cm.
- B. Monthly mean air temperature with highest maximum and lowest minimum values.
- C. Percentage of days in which the wind blew from the easterly quarter (NE, E, SE) (discontinuous line).
Percentage of days in which the wind blew from the westerly quarter (NW, W, SW) (continuous line).
- D. Number of days on which wind force exceeded 4 on Beaufort scale.

FIG. 1.7

BAY OF ISLANDS

Surface seawater temperatures ($^{\circ}\text{C}$)

- A. Observations for 1970-71.
- B. Mean surface temperature (derived from A.)
compared to air temperature at Waitangi Meteorological Station.
- C. Observations at Russell, 1929-39 (Hefford, 1947)
- D. Observations at Russell and Cape Brett, 1929-32
(Hounsell, 1935).

FIG. 7

FIG.1.8

BAY OF ISLANDS

Subsurface temperatures, ($^{\circ}\text{C}$), at Confluence and Waewaetoria hydrological/plankton stations. Temperatures were taken with a mercury thermometer read to 0.2°C at both stations.

FIG.1.9

BAY OF ISLANDS

Surface temperatures ($^{\circ}\text{C}$) and salinities ($^{\circ}/\text{oo}$)

- A. Surface temperatures 15/9/71
- B. Surface salinities 15/9/71
- C. Surface temperatures and salinities 2/10/70.

On both days temperatures were taken with a mercury thermometer read to 0.1°C and salinity determinations were made with a Beckman RS7B salinometer.

Fig. 8

Fig. 9

FIG. 1.10 BAY OF ISLANDS

Temperature profiles ($^{\circ}\text{C.}$) and surface salinities ($^{\circ}/\text{oo}$)
5/2/71.

- A. Bathythermograph stations and surface salinities.
- B. Surface temperatures.
- C. Bathythermograph profiles.

Surface temperatures were taken with two mercury thermometers read to 0.1°C. and the readings averaged.

Surface salinity determinations were made with a Beckman R37B salinometer.

FIG. 10

FIG.1.11 BAY OF ISLANDS

Temperature profile ($^{\circ}\text{C}.$) 15/9/71.

A. Bathythermograph stations.

B. Bathythermograph temperature profile.

 Isotherms at 0.2°C intervals.

FIG. 11

TABLE 1.4

BAY OF ISLANDSSURFACE TEMPERATURES AND SALINITIESWinter (28/5/71)

<u>Station</u>	<u>Temp.(°C)</u>	<u>Salinity (°/oo)</u>	<u>Temp(°C)</u>	<u>Salinity (°/oo)</u>
Confluence	16.0	-	16.2	35.006
Brampton Reef	16.0	34.646	16.0	33.062
Waewaetoria	17.4	35.525	16.2	35.279
Cape Brett	18.2	35.718	17.8	35.811
East Cape Brett	18.6		17.8	
(2 miles)				

Temperatures from mercury thermometer read to 0.2°C, salinities determined with Beckman RS7B salinometer.

TABLE 1.5

BAY OF ISLANDSFURTHER SURFACE SALINITY DATA (°/oo)

		<u>Confluence</u>	<u>Brampton Reef</u>	<u>Waewaetoria</u>
1970	22/4	35.30	35.20	35.50
	30/8	34.30	34.33	
	2/10	30.33	27.02	34.54
	5/10	33.94	33.05	
	3/11	31.53	33.32	31.96
	7/11	31.52	32.55	
	27/12	35.37	35.26	35.60
1971	9/1	34.45	33.77	35.38
	4/2	35.44	35.34	
	27/4	35.43		35.53
	28/5	35.14	34.65	35.53
	29/6	35.01	33.06	35.38
	10/9	34.02	33.28	35.08
	24/10	33.84	31.56	
	3/12	34.84	34.81	35.04

Salinities determined with Beckman RS7B salinometer.

TABLE 1.6BAY OF ISLANDSFURTHER SUBSURFACE SALINITY DATA (°/oo)

		<u>Confluence</u>	<u>Brampton Reef</u>	<u>Waewaetoria</u>
3/11/70	surface	31.53	33.32	
	8m	35.28	34.86	
	15m	35.21	35.05	
<hr/>				
7/11/70	surface	31.52	32.55	
	8m	34.78	34.70	
	15m	34.67	34.95	
<hr/>				
27/4/71	surface	35.43		35.53
	8m	34.82		35.53
	14m	34.99		
<hr/>				
28/5/71	surface			35.53
	8m			35.32
<hr/>				
29/6/71	surface	35.01		
	15m	35.43		
<hr/>				

FIG. 1.12

BAY OF ISLANDS

SURFACE SALINITIES ($^{\circ}/_{\text{oo}}$) 8/2/71

A. Outgoing tide.

B. Incoming tide.

Salinity determinations were made with the Beckman
RS7B salinometer.

FIG. 1.13

BAY OF ISLANDS

SECCHI DISC TRANSECTS

Values give the Secchi Disc visibility distance in metres.

Fig 12

Fig 13

TABLE 1.7

BAY OF ISLANDS

DISSOLVED OXYGEN CONTENT

Date	Station	Depth (m)	Temperature (°C)	Dissolved O (ml/l)	Dissolved O (% sat.)
30/7/70	South Brampton Reef.(0900)	3	14.2	5.58	>100
		8	14.1	5.54	>100
	North Brampton Reef (0930)	3	14.0	5.89	>100
		15	14.1	5.31	65
	Waewaetoria (10 45)	3	14.1	6.22	>100
		8	14.0	6.36	>100
		15	14.2	6.30	74
	Waewaetoria (12 00)	5	14.5	5.91	>100
		15	14.4	5.98	74
	Waewaetoria surface (14 15)		14.3	6.57	>100
		8	14.2	6.29	>100
		14	14.2	6.40	79
3/11/70	Confluence (13 30)	surface	18.4	6.14	>100
		8	18.4	5.67	>100
		15	18.3	5.67	76
	Brampton Reef (14 00)	surface	17.2	5.28	100
		8	17.1	5.19	>100
		15	17.2	5.17	67
14/2/71	Middle Harbour	5	24.1	5.18	>100
		5	20.2	5.67	>100

4. Turbidity.

The results of a winter and a summer transect using a Secchi Disc for turbidity measurements are shown in Fig. 1.13 (a) and (b). Observations at the three hydrological stations in Bay of Islands are given in Table 1.8.

TABLE 1.8

BAY OF ISLANDS

FURTHER SECCHI DISC READINGS (SD)

Date	Sea	Sky	Confluence SD(m)	Brampton Reef SD(m)	Waewatoria SD(m)
25/5/70	Calm	Clear	5.5	4.5	
3/11/70	Mod. chop.	Lazy	3.5	2.0	11.0
6/11/70	Calm	Clear	3.5	2.5	
4/12/70	Calm	Clear	4.0	3.0	11.0
30/6/71	Mod. chop	Clear	4.5	4.5	12.5

In the midsummer of 1971 Secchi disc readings were taken at the Confluence over a complete tidal cycle. The Secchi disc visibility values ranged from 1.5m to 3.0m, with the greatest turbidity occurring during the flood tide. (Fig 4.4).

5. Current System.

The probable transit paths of drift cards released and recovered in Bay of Islands are shown in Fig. 1.14 (A-E). The wind direction and force taken daily at 0900 at the Waitangi Meteorological office for twenty days subsequent to the release are also given.

Fig. 1.14(F) shows the transit paths of the two drift drogues recovered from the five released during 1971.

The drift of cards released at five stations outside the Bay on 27/2/72 and 4/3/72 are shown in Fig. 1.15.

FIG.1.14

BAY OF ISLANDS
DRIFT CARD AND DRIFT DROGUE RELEASES

Probable transit paths of drift cards and drogues released in Bay of Islands, and subsequent wind observations.

Each line represents the movement of one card or drogue.

A-E Drift cards: Release stations are marked with percentage recovery; total percentage recovery is given below each date of release.

F Average percentage recovery from drift card release stations (derived from A - D) and probable transit paths of two drift drogues with dates of release and recovery.

Wind observations in A - D are shown on the right of the figure and are based on 0900 hours readings at Waitangi Meteorological Station for the subsequent twenty days. Radiating lines give the direction in which the wind is moving. Thin lines are winds of Beaufort force 1 - 2; medium lines 3 - 4, and thick lines > 4 . Length of line is proportional to the number of days.

FIG.1.15 RECOVERY OF DRIFT CARDS RELEASED OFF BAY OF ISLANDS

Fifty cards released at each station:

Stations 1 - 4 on 27/2/72; Station 5 on 3/3/72.

A continuous line represents the path of two cards;

a dotted line represents the path of one card.

Percentage recoveries are given at each station.

Total recovery was 22%.

Daily 0900 hours and 1300 hours wind directions and force (Waitangi) for the subsequent two weeks are given.

FIG. 14

FIG. 14 cont

FIG. 15

WELLINGTON HARBOUR(A). PHYSIOGRAPHY AND GENERAL HYDROLOGY.

Wellington Harbour (Port Nicholson) is an embayment of thirty square miles, and is morphologically defined as a hill and valley system drowned by the post-glacial rise in seawater (Van der Linden, 1967). Its physiography is described by Bell (1907 and 1909), Cotton (1911, 1913) and Maxwell (1956). Its shores vary from silt at Petone Beach to pebble and sand beaches in more open areas. Water depths (Fig. 1.16) reach 25 metres (13 fathoms) southwest of Somes Island, while Gilmour (1960b) gives the average depth as about 21 metres (11 fathoms). Bottom sediments are described by Van der Linden (1967); Fig. 1.17 taken from that study, gives the grain size distribution.

Brodie (1958) estimates the total catchment area of Wellington Harbour to be 280 square miles. The main freshwater source is the Hutt River, which Johannessson (1958) estimates to have a catchment area of 244.14 square miles. Maxwell (1956) gives its minimum and maximum daily freshwater flows as 2.6×10^6 tons and 180×10^6 tons respectively.

Accounts of the geology of the region include Stevens (1956), Brodie (1957), and Lauder (1962). Most of the Wellington Peninsula bedrock is Mesozoic greywackes.

The currents of Cook Strait, off the entrance to Wellington Harbour, are influenced mainly by tidal height differences and by the D'Urville and Southland Currents. Brodie (1958) describes the tidal currents in the Harbour; in its simplest form the tide floods northwards and ebbs southwards in the western part of the harbour. Water velocities vary from half knot at the mouth to quarter knot or less in the inner harbour. Gilmour (1960b) gives the range of the tide between high and low tide as varying between three and four feet, (about 0.95 to 1.25 metres).

The channel connecting the harbour to the open sea is large enough to ensure good mixing of the harbour water with that outside. (Gilmour, 1960 and Maxwell, 1956).

FIG. 1.16

Wellington Harbour.

Hydrological/plankton and temperature
recording stations.

Depth contours (fathoms) (from Van der Linden, 1967)
the 13 fathom contour is the 24.5 metre contour,
the 10 fathom contour is the 19 metre contour,
the 6 fathom contour is the 11.5 metre contour,
and the 3 fthm. contour is the 5.5 metre contour,
approximately.

Fig. 1.17

Wellington Harbour.

Grain size distribution (from Van der Linden, 1967)

FIG. 16

FIG. 17

Hefford (1947) gives winter surface salinities of 34.5-35.0 ‰ for Cook Strait, but the harbour is more diluted and is frequently 2 ‰ lower than the Cook Strait waters.

Gilmour (1960b) gives the annual range of Wellington Harbour surface seawater temperatures as 10.5°C in August and 17.2°C in February.

General harbour organic and inorganic pollution is discussed by Maxwell (1956) who concluded that it was negligible as an ecological factor at that time, excepting near the sources of contamination.

(B) CLIMATE.

Gabites (1960) discusses the climate of Wellington, with its windiness and its lack of extreme temperatures due to its closeness to the sea and the constant wind.

Extracts from the Climatological table for Kelburn are given in Fig. 1.18 (New Zealand Meteorological Service, 1966).

Kidson (1931b) shows Wellington to be in the 54°-55°F. annual sea-level air isotherm with a low annual variability of temperature. The average annual rainfall at Kelburn is 125 cm. (New Zealand Meteorological Service, 1966) with January-March normally the driest months, and July the wettest (Seelye, 1944). This is Type A of the rainfall classification of Kidson (1931a). Very heavy rain is commonly associated with southerly winds or southerly changes. Rain falls just less than 8% of the time (Gabites, 1960). Seelye (1940) gives the variability of annual rainfall of the region as 12-16%, which is a medium value for New Zealand.

The most frequent prevailing wind directions for 1939-1948 were northwest (32.2% of the time) and south (17.5% of the time), (New Zealand Meteorological Service, 1966). Watts (1947) records twentyeight gales per year for the area, which is the highest annual frequency in the country. Wellington also lies in the highest maximum wind gust region, with winds reaching 90-99 miles per hour (de Lisle, 1965). There is an average of six thunderstorms per year (Watts, 1947).

The average annual sunshine hours is 1900 (Watts, 1947), 18% of the possible (Gabites, 1960).

Kidson and Crust (1932) note an average diurnal variation of air temperature of 9°F . in summer and 5°F in winter for 1928-31.

Frosts occur occasionally, Kelburn having an annual average of 17.9 days of ground frost for the period 1928-1960 (New Zealand Meteorological Service, 1966).

Finkelstein (1961) estimates the annual open water evaporation as 68.7 cms., which is about average for New Zealand.

Macky (1938) compares climatological observations made at Eastbourne and Kelburn and notes considerable differences, particularly in air temperatures, with Eastbourne being an average of 2.1°F . warmer than Kelburn. Surface water temperatures at each side of the harbour may be expected to show similar differences under certain weather conditions.

(C) HYDROLOGICAL OBSERVATIONS FOR WELLINGTON HARBOUR 1970-71

1. Temperature.

Surface seawater temperatures were taken regularly at three points in the harbour during 1970-72, and the observations are given in Table 1.9.

- (1) At Somes Island, temperatures were taken off the wharf at 0800 hours.
- (2) At Point Howard, temperatures were taken off the wharf at 0900 hours.
- (3) At Queens Wharf, temperatures were taken off M.V. "Tirohia" at 0900 hours.

The temperatures at Somes Island and Point Howard were taken with mercury thermometers read to 0.2°C ., while Queens Wharf temperatures were taken with the Murayama Electronic thermorecorder.

Fig. 1.19 compares the monthly mean surface seawater temperatures from Table 1.9 with monthly mean values of previous records.

Subsurface seawater temperatures. Observations were made approximately monthly at the four hydrological stations in Wellington Harbour (Fig. 1.16). Further stations used are described later.

Isopleth diagrams for the seasonal variation of subsurface

temperatures at hydrological stations 1, 2 and 4 are given in Fig.1.20. Fig.1.21 gives monthly temperature profiles between stations 1 and 2, 4 and 2, and 4 and 3. Figs.1.22 -1.26 describe the winter temperatures and salinities in the harbour. Fig.1.22 shows surface temperatures taken on the ebb tide on 14/5/70. The colder surface water of the Hutt River is seen meeting the warmer harbour and harbour entrance water. Fig.1.23 gives a profile from near the mouth of the Hutt River to the harbour entrance taken during the ebb tide on 14/6/70. The opposing tongues of the warm Cook Strait water and the cooler Hutt River water are evident.

Fig.1.24 gives a temperature/salinity profile of the western and central harbour taken during the flood tide on 17/6/70. Warmer and more saline water often lies in deeper parts of the harbour, although low salinity did occur off station 2, at 20m depth. This is possibly due to subterranean freshwater leakage, which has been reported in the harbour. The cooler and less saline water of the Hutt River remains close to the surface in stations 3 and 4.

Fig.1.25 gives surface and sub-surface temperatures and salinities taken during the flood tide on 6/7/70. The sections of tongues of low salinity water at stations 6 and 4 in Fig.1.25 (B) and (F) also suggest possible subterranean freshwater leakages. Clearly seen are the low salinity surface water at the mouth of the Hutt River and the higher salinity and warmer water at the harbour entrance. Warm water in deeper parts of the harbour may be associated with subterranean freshwater leakages. The cooler and less saline water of the Hutt River extends along Petone Beach at stations 6, 5 and 4.

Transects made of the harbour on 26/7/71 are given in Fig.1.26. The stations are given in Fig.1.26(A), while harbour surface salinities appear in Fig.1.26(B). East-west harbour temperature profiles (Fig.1.26C) show little variation between ebb and flood tides, with warmer water confined to the bottom in deeper areas. This warm water may be associated with the low salinity subterranean leakages south of Somes

TABLE 1.9

WELLINGTON HARBOUR SURFACE SEAWATER TEMPERATURES °C

1. Somes Is Wharf
2. Point Howard Wharf
3. Queen's Wharf

Number of Observations (days)				Highest Recording			Lowest Recording			Mean Recording			Overall Mean
1	2	3		1	2	3	1	2	3	1	2	3	
1970													
A	9	9											12.3
M	17	3											11.0
J	16	3											11.0
J	20	15											10.6
A	19	9											11.8
S	23	12											13.2
O	21	17											14.8
N	26	12											16.8
D													
	23												
	28	9											17.6
J	14	7											18.7
F	22	13											17.6
M	29	14											16.1
A	31	14											14.6
M	30	14											12.9
J	29	12											10.7
J	31	13											11.1
A	28	15											11.6
S	31	10											12.7
O	28	4											14.7
N	22	10											15.8
D	20	13											17.4
J	22	10											17.1
F	22	8											17.3
M	20	13											15.7
A													13.4
M													

FIG.1.18

WELLINGTON

METEOROLOGICAL OBSERVATIONS FOR KELBURN

(from New Zealand Meteorological Service, 1966)

- A. Mean air temperature ($^{\circ}\text{C}$), with mean monthly maxima and minima (1945-60).
- B. Mean rainfall (inches) (1921-50).
(Scale in cm. is 0, 10.2 and 20.4)

FIG.1.19

WELLINGTON HARBOUR

SURFACE SEAWATER TEMPERATURES ($^{\circ}\text{C}$)

- A. Observations from three temperature recording stations
 - (1) Somes Island.
 - (2) Point Howard. see Fig.1.16.
 - (3) Queen's Wharf.
- B. Mean value derived from above.
- C, D, E Previous observations.

FIG. 18

FIG. 19

Island. Fig.1.26(D) shows the warmer water of Cook Strait "pouring" over the sill at the harbour entrance.

Seawater temperatures were observed at 3m, 8m and 12m over tidal cycles at Mahanga Bay in late winter 1970, and mid and late summer of 1971. The temperatures showed no marked stratification, and varied by no more than 1.5°C. during the cycles.

2. Salinity. Surface salinities taken at the four hydrological stations in the harbour are given in Table 1.10.

TABLE 1.10

WELLINGTON HARBOUR

	Surface Salinities (°/oo)							
	15/10	<u>1970</u> 16/11	10/12	21/12	14/1	<u>1971</u> 21/2*	7/3*	29/3*
1. Mahanga Bay	34.152	34.081	34.738	34.440	34.448	33.2	34.5	32.2
2. S.W.Somes Island	33.612	34.087	34.756	34.424	34.574	33.8	34.7	32.3
3. Petone Beach	33.913	27.146	34.749	33.746	31.970	33.2	-	32.7
4. Ngauranga	34.100	34.150	34.509	34.605	34.359	-	34.3	32.0
	22/4*	12/5*	11/6	7/7	2/9*	7/10*	15/11*	
1. Mahanga Bay	34.7	33.6	34.639	33.827	32.7	31.0	33.2	
2. S.W.Somes Island	34.7	33.8	34.376	34.080	32.7	30.3	33.7	
3. Petone Beach	34.0	32.7	34.362	34.467	32.7	21.8	25.3	
4. Ngauranga	34.0	33.8	34.366	33.353	33.3	24.5	33.7	
	16/12*	1972 2/2*						
1. Mahanga Bay	30.8	32.5						
2. S.W.Somes Island	31.6	31.8						
3. Petone Beach	30.8	29.3						
4. Ngauranga	32.8	31.8						

* Determination by Zeal hydrometer. Others by Beckman RS7B Salinometer.

Surface salinities were measured at some high and low tide slack waters over five days in June 1971, and the results are given in Table 1.11. The range in high tide slack water readings was small (approximately $0.15^{\circ}/\text{oo}$).

TABLE 1.11.

WELLINGTON HARBOURVARIATIONS IN SURFACE SALINITIES ($^{\circ}/\text{oo}$) AT MAHANGA BAY

14/6/71 - 18/6/ 71

	14/6	15/6	16/6	17/6	18/6
H.T.surface salinity	34.454	34.544	34.599	-	34.519
L.T.surface salinity	34.507	-	34.451	-	-

Determination by Beckman RS7B Salinometer.

Harbour salinity profiles, already referred to, were given in Figs. 1.24, 1.25 and 1.26.

Further subsurface salinities from two of the harbour hydrological stations are given in Table 1.12.

TABLE 1.12

WELLINGTON HARBOURFURTHER SUBSURFACE SALINITIES ($^{\circ}/\text{oo}$)

24/11/70	<u>S.W.Somes Island</u>		<u>Ngauranga</u>	
8m	34.371		34.364	
15m	34.388		34.310	
21/12/70				
surface	34.424		34.605	
15m	34.575		34.318	
25/2/71	<u>S.W.Somes Island</u>			
	<u>10.30</u>		<u>13.30</u>	<u>16.00</u>
Surface	18.9 $^{\circ}$ C 34.738	18.8 $^{\circ}$ C 34.654	18.7 $^{\circ}$ C 35.132	
2m	18.9 $^{\circ}$ C	18.8 $^{\circ}$ C	18.7 $^{\circ}$ C	
4m	18.9 $^{\circ}$ C 34.725	18.8 $^{\circ}$ C 34.659	18.7 $^{\circ}$ C	
6m	18.9 $^{\circ}$ C	18.7 $^{\circ}$ C	18.7 $^{\circ}$ C	

TABLE 1.12 (contd.)

25/2/71	S.W.Somes Island					
		10.30		13.30		16.00
	8m	18.8°C		18.7°C		18.7°C
	10m	18.7°C	34.786	18.7°C		18.7°C 35.230
	15m	18.4°C	35.379	18.5°C	35.037	18.7°C 35.129
	20m	18.2°C		18.2°C		18.6°C
	22m	18.1°C		18.0°C		18.5°C

All determinations were made with the Beckman RS7B Salinometer.

Salinities observed at 3m, 8m and 13m over a complete tidal cycle in midsummer, 1971 at Mahanga Bay, showed no marked stratification, with values ranging by less than 0.05‰ from 34.5‰ during the tidal cycle. A similar observation in late winter 1970 at the same station again showed no stratification, and variations of less than 0.1‰ from 34.1‰.

3. Dissolved Oxygen.

Per cent oxygen saturation values were observed at 3M, 8M and 13M over a complete tidal cycle in midsummer 1971 at Mahanga Bay. The values varied little during the tidal cycle, and all exceeded 100% saturation.

Further per cent oxygen saturation values at harbour stations are shown in Table 1.13.

TABLE 1.13

WELLINGTON HARBOUR

FURTHER DISSOLVED OXYGEN VALUES.

Date	Station	Depth (m)	Temperature (°C)	Dissolved O (ml/l)	Dissolved O (% saturation)
24/11/70	Ngauranga (a.m.)	8	15.2	7.65	>100
	S.W.Somes Is (a.m.)	8	15.0	6.32	>100
12/5/70	Mahanga Bay (p.m.)	surface	13.1	6.03	>100
		8	12.6	5.98	>100

TABLE 1.13 (contd.)

Date	Station	Depth(m)	Temperature (°C)	Dissolved O (ml/l)	Dissolved O (% saturation)
13.5.70	Evans Bay (P.M.)	surface	12.7	6.18	>100
		4	12.6	6.01	>100
16/5/70	Mahanga Bay (a.m.)	surface	12.3	6.21	>100
		2.5	12.3	6.35	>100
		4	12.3	6.12	>100
	Mahanga Bay (p.m.)	surface	12.5	6.28	>100
		4	12.7	7.28	>100
28/9/70	Mahanga Bay (a.m.)	10	12.7	5.52	99
	Harbour mouth (a.m.)	surface	12.4	5.63	97
		12	12.3	5.48	83
	S.E.Somes Is. (a.m.)	surface	12.2	5.62	97
		15	12.4	5.63	67
	S.W.Somes Is.(a.m.)	surface	12.4	5.90	>100
		15	12.6	5.52	66
	off Petone Beach (p.m.)	surface	12.8	5.48	96
		15	12.7	5.31	64
	Ngauranga (p.m.)	surface	12.7	5.48	94
		15	12.7	5.88	71

4. Turbidity.

Secchi Disc transects of the harbour were made on 24/11/70 and 26/7/71 to determine the range of turbidity in the harbour under normal river discharge conditions. The results are given in Fig. 1.27(A) and (B).

FIG.1.20

WELLINGTON HARBOUR

Temperature profiles ($^{\circ}\text{C}.$) against depth (m) and time for hydrological/plankton stations 1, 2 and 4 (Mahanga Bay, S.W.Somes Island, and Ngauranga).

Isotherms at 0.5°C intervals.

Temperatures were taken with the Murayama electronic thermorecorder.

FIG. 20

FIG.1.21.

WELLINGTON HARBOUR

Temperature profiles ($^{\circ}\text{C}.$) between hydrological/plankton stations during the sampling period 1970-72.

1 and 2 (Mahanga Bay and S.W.Somes Island).

4 and 2 (Ngauranga and S.W.Somes Island).

4 and 3 (Ngauranga and Petone Beach)

Isotherms at $0.2^{\circ}\text{C}.$ intervals.

Temperatures were taken with the Murayama electronic thermorecorder.

FIG. 21

FIG.1.22 WELLINGTON HARBOUR

Surface temperatures, ($^{\circ}\text{C}$) 14/5/70.

Isotherms at 0.5°C intervals.

Temperatures were taken with a mercury thermometer read to 0.1°C .

FIG.1.23 WELLINGTON HARBOUR

Temperature profile, ($^{\circ}\text{C}$) 14/6/70.

Isotherms are 0.2°C intervals.

Temperatures were taken with the RH5 salinometer.

FIG.1.24 WELLINGTON HARBOUR

Temperature ($^{\circ}\text{C}$) and salinity ($^{\circ}/\text{oo}$) profiles, 17/6/70,
taken with the RH5 salinometer.

Isotherms at 0.2°C intervals.

Isohalines at $0.2^{\circ}/\text{oo}$ intervals.

A. Stations.

B. Temperature profile.

C. Salinity profile.

FIG. 22

14-5-70 °C

FIG. 23

FIG. 24

DEPTH (M)

FIG.1.25

WELLINGTON HARBOUR

Salinity ($^{\circ}/\text{oo}$) and temperature ($^{\circ}\text{C}$) profiles, 6/7/70
taken with the RH5 salinometer.

A Stations.

B-G Profiles.

Isotherms at 0.2°C intervals

Isohalines at $0.2^{\circ}/\text{oo}$ intervals.

FIG. 25

FIG.1.26

WELLINGTON HARBOUR

Temperature ($^{\circ}\text{C}$) and salinity ($^{\circ}/\text{oo}$) profiles 26.7.71.

1. Stations.
2. Surface salinities on the ebb tide.
Isohalines at $0.5^{\circ}/\text{oo}$ intervals.
3. Transect 1 - temperature profile on ebb and flood tides.
Isotherms at 0.2°C intervals.
4. Transect 2 - temperature profile at low water slack.
Isotherms at 0.2°C intervals.

Temperatures were taken with the Murayama electronic thermorecorder,
and salinities with the Zeal hydrometer.

FIG. 26

Table 1.14 gives further Secchi Disc visibility values from the harbour.

Secchi Disc values over tidal cycles in late winter 1970 and mid and late summer 1971 at Mahanga Bay varied by less than 0.25M with greatest turbidities occurring at flood and ebb tides.

WELLINGTON HARBOUR
FURTHER SECCHI DISC VISIBILITY VALUES

TABLE 1.14

Date	Station	SD(m)	Sea	Sky
16/5/70	Mahanga Bay	6.0	Calm	Clear
28/9/70	Mahanga Bay	3.5	v.choppy	Clear
	Harbour mouth	3.5		
	Ward Island	3.5		
	S.W.Somes Island	4.0		
	Petone Beach	2.25		
	W.Petone Beach	3.5		
	Ngauranga	2.75		
15/10/70	Mahanga Bay	4.5	v.choppy	overcast.
	S.W.Somes Is.	4.75		
	Petone Beach	4.0		
	Ngauranga	3.0		
24/11/70	Mahanga Bay	4.5	calm	clear
	S.W.Somes Is.	4.75		
	Ngauranga	4.5		
10/12/70	Mahanga Bay	3.5	light chop	hazy
	S.W.Somes Is.	3.25		
	Petone Beach	2.5		
	Ngauranga	2.5		

TABLE 1.14 (contd.)

Date	Station	SD(m)	Sea	Sky
21/12/70	Mahanga Bay	5.0	Calm	Clear
	S.W.Somes Is.	5.0		
	Petone Beach	3.75		
	Ngauranga	2.5		
25/2/71	S.W.Somes Is.	3.5	moderate chop	Cloudy
1/3/71	Mahanga Bay	6.0 6.5	calm	clear
		4.5	moderate chop	cloudy
14/6/71	Mahanga Bay	5.25	light chop	clear
15/6/71	" "	5.5	calm	clear
16/6/71	" "	6.0	calm	slight haze
18/6/71	" "	4.5	light chop	cloudy

FIGURES

1.27 and 1.28

FIG.1.27

WELLINGTON HARBOUR

Secchi Disc visibility values

(m)

Isolines at 0.5m intervals.

FIG.1.28

Proposed current pattern for Bay of Islands.

Fig. 27

Fig. 28

Differences in the hydrology between Bay of Islands and Wellington Harbour are due not only to their latitude, but also to their physiography. Bay of Islands is some 6° latitude north of Wellington, and is a large wide coastal indentation which allows an oceanic influence to reach to the base of its estuaries. Wellington Harbour has a shallow entrance four miles in length and one to two miles wide, which restricts its oceanic influence.

A. CLIMATIC DIFFERENCES.

Climatic differences between Bay of Islands and Wellington include

- (a) Bay of Islands has higher air temperatures. The average monthly mean air temperature for 1945-60 at Kerikeri, Bay of Islands was 2.5° - 3.0° C. higher than for Kelburn, Wellington. Also, the mean monthly maximum was 3.0° - 4.0° C. higher and the mean monthly minimum up to 1.0° C. higher for the same period.
- (b) Winds are more frequent and stronger at Wellington, causing greater mixing and movement of water. The prevailing wind directions at Wellington are north west and south; while at Bay of Islands they are north east and south west.
- (c) Bay of Islands has a greater average annual rainfall which affects the surface seawater salinity. The variability of annual rainfall is also greater than Wellington Harbour, perhaps making likely greater differences between years of observations.
- (d) The monthly mean total radiation is about twentyfive langley's/day less at Wellington than Bay of Islands. This affects evaporation and phyto-plankton productivity.

B. HYDROLOGICAL DIFFERENCES.

1. Temperature.

Important factors affecting the water temperature of both harbours are the amount of solar heating, the oceanic influence and the freshwater inflow.

(a) Surface seawater temperatures closely follow air temperatures at both harbours (Figs. 1.7 and 1.19), a trend widely reported in New Zealand (Ralph and Hurley, 1952, Jillett, 1971, etc.).

The monthly mean sea temperature exceeds the monthly mean air temperature at all times of the year. The water temperatures, like the air temperatures, are lower at Wellington Harbour than Bay of Islands. Monthly mean air temperatures averaged 2.55°C . less, and monthly mean surface seawater temperatures 4.08°C . less in Wellington than Bay of Islands for 1970-71.

In Bay of Islands the maximum monthly mean surface seawater temperature (23°C) occurred in February, and the minimum (15°C) in July and in 1971, these coincided with the respective times of maximum and minimum air temperatures. Hefford (1947) also recorded the maxima in February and minima in July for the surface seawater temperatures at Russell for 1929-39 (Fig. 1.7c). However, Hounsell (1935) gave maxima in March, January and February, and minima in July and August for the years 1929-39. (Fig. 1.7d gives the mean annual temperature curve).

The monthly mean surface temperatures at Russell during 1970-71 (Fig. 1.7a) averaged 1.57°C . more than the surface temperature values of Hefford (1947) at Russell for the period 1929-39. Also, the monthly mean surface temperatures at Russell of Hounsell (1935) for 1929-30, 1930-31 and 1931-32 averaged 1.83°C , 1.91°C . and 2.26°C . respectively, cooler than the 1970-1 surface temperatures at Russell. Hefford's figures may well have had the same source as those of Hounsell. Neither author referred to the number or time of day of their observations, these being factors which can cause undue variations in temperatures. For example, Skerman (1958) reported diurnal variations of 4.0°C . in surface waters in summer in Wellington Harbour. In the present study, two thermometers were used, one at Russell and one at Otehei Bay and Wairoa Bay, and the number of observations on which the monthly average is based is recorded (Table 1. 3);

the results for both the thermometers show consistently higher temperatures than the earlier records.

Hurley and Burling (1960) reported early surface sea temperature records from Portobello, Otago Harbour, being approximately 3.0°C less than recent ones, and they attributed the difference to constant errors in calibration. This is the probable cause of the discrepancies between the earlier and present records from Bay of Islands.

For Wellington Harbour, Gilmour (1960b) gives maximum surface seawater temperature as 63°F . (17.2°C .) in February and minimum as 51°F . (10.5°C .) in August. The surface data of Maxwell (1956) is generally consistent with this, but Ralph and Hurley (1952), Skerman (1956) and Wear (1965) give greater annual temperature ranges ($8.55^{\circ} - 20.0^{\circ}\text{C}$.), with maxima occurring either in January or February, and minima in July or August. The surface temperatures in Fig.1.19 for 1970-72 show maxima in February 1971 and January 1972, and minima in August 1970 and July 1971, with an annual temperature range of 8.1°C ($10.6^{\circ} - 18.7^{\circ}\text{C}$.) These values for 1970-72 are in general agreement with the earlier records, and do not show the discrepancy seen in the Bay of Islands temperatures.

During 1970-71 Wellington harbour surface water temperatures decreased at 1.75°C . per month from mid-March to mid-July, and increased at 1.5°C and 1.2°C . from mid-August to mid-December (cf. 1.7°C and 1.5°C . respectively for Wellington Harbour 1953-5 given by Skerman, 1958, and 1.62°C . and 1.42°C . respectively for Bay of Islands, 1970-71).

Skerman (1958) noted two sorts of surface temperature fluctuations in Wellington Harbour thermograph recordings - irregular variations possibly suggesting stratification in surface waters, and periodic diurnal variations, the latter reaching considerable proportions (up to 4°C .) in summer. Wear (1965) noted similar short period fluctuations. The effect of the diurnal variation is minimised in this study because surface temperatures were taken at the same time of the day. No observations were made on stratification in the surface waters.

Bay of Islands shows greater variations in surface temperatures within the harbour at any particular time than Wellington Harbour because of the more direct oceanic influence. The shallow estuarine areas, which do not occur in Wellington Harbour, lack the stabilising effect of a large body of water, and therefore heat and cool more rapidly. The curves for the Bay of Islands surface temperature stations in Fig.1.7(a) show little difference because readings are discontinuous, and although widely separated in the harbour, all three stations are in sheltered localities. However, Fig.1.8, comparing surface temperatures at the estuarine Confluence hydrological station with those of the outer harbour Waewaetoria hydrological station, shows annual surface temperature ranges of 9.0°C . and 6.5°C . respectively. In Fig.1.7(d), Hounsell (1935) depicted to some extent this effect between the surface temperatures for Russell (inner harbour) and Cape Brett (outer harbour), with annual ranges of 7.9°C . and 7.3°C . respectively for the period 1929-1932.

Table 1.4 depicts the winter situation for Bay of Islands with surface temperatures up to 2.5°C . less in estuarine areas than in near coast open waters. Figures 1.9 (A) and (C) give the spring situation with harbour surface values varying by less than 1.0°C . In mid-summer (Fig.1.10 B) inner harbour waters are up to 2.0°C . warmer than those of the near coast open waters. Skerman (1958) reported similar trends for Otago Harbour and Lyttleton Harbour.

In Wellington Harbour temperature conditions are more homogeneous, with the zone of change from near coast open water temperature conditions to harbour temperature conditions confined to a narrow band at the harbour mouth. Fig.1.19(a) shows the more enclosed Queen's Wharf temperature station cooling during autumn and warming during spring at a slower rate than the other two harbour stations. The Point Howard temperature station experiences the coolest winter temperatures because of the cold Hutt River water, while Queen's Wharf is warmest because of its shelter from the Hutt River and from prevailing winds. The higher air temperatures at

Eastbourne than Kelburn, noted by Macky (1938), may give higher surface water temperatures to eastern parts of the harbour which are not directly influenced by the Hutt River.

Greatest monthly surface temperature ranges occurred at the two more exposed stations, both of which are most subject to sea surface and air temperature changes.

Maxwell (1956) suggested that the normal freshwater inflow of the Hutt River is insufficient to upset the hydrological regime of the harbour, but under flood conditions total freshwater inflow into the harbour modified both temperature and salinity structures. The effect of the Hutt River on surface temperatures under normal discharge conditions on 14/5/70 is shown in Fig. 1.22; surface temperatures in the path of the Hutt River as far south as Somes Island are noticeably reduced. In the profiles in Figs. 1.23 to 1.26 the direct influence of the Hutt River also under normal discharge conditions is seen to occur in surface areas only. These diagrams support Maxwell's contention, with temperature and salinity differences being rapidly dissipated by the complex tidal current pattern. But after heavy rainfall the entire harbour surface becomes diluted, as demonstrated by the low salinity values of Brodie (1958), and the values in Table 1.10 for 29/3/70, 12/5/70, 2/9/70 and 7/10/70/.etc.

The difference between near coast Cook Strait and harbour surface temperatures varies seasonally. The influence of oceanic waters on the harbour temperatures in winter is shown in the profile at the harbour entrance in Fig. 1.26. Near coast Cook Strait surface water temperatures exceed harbour surface temperatures by about 2.0°C ., while the water of the Hutt River may be up to 4.0°C . cooler than Cook Strait. This is considerably more than the value of 2.5°C . suggested by Maxwell (1956).

Garner (1953) drew the 51°F . (10.5°C .) surface isotherm off the mouth of Wellington Harbour on 19/20 October, 1950 (Spring). Surface harbour temperatures in October 1970 and 1971 were $12^{\circ} - 13^{\circ}\text{C}$,

approximately 2.0°C . higher than Cook Strait.

In summer, the temperature difference increases. Garner (1961) showed the 14.0°C . surface isotherm off Wellington in February 1955, when surface harbour temperatures were up to 18.0°C .

Table 1.15 summarises the differences in surface temperatures between Cook Strait and Wellington Harbour. The Cook Strait canyon ^{are} temperatures/taken from Heath (1971).

TABLE 1.15 COMPARISON OF MONTHLY SURFACE SEAWATER TEMPERATURES

Date	Wellington Harbour Temperature ($^{\circ}\text{C}$)	Cook Strait Canyon Temperature ($^{\circ}\text{C}$.) (from Heath, 1971)	Difference ($^{\circ}\text{C}$.)
1/10/68	12.0	10.5	+1.5
5/11/68	14.0	11.5	+2.5
18/2/69	18.0	15.0	+3.0
22/4/69	16.5	15.0	+1.5
17/6/69	11.5	13.0	-1.5
22/7/69	10.0	12.0	-2.0
9/9/69	12.0	12.5	-0.5
7/10/69	12.5	11.0	+1.5

(b) Subsurface seawater temperatures. Few observations could be made on subsurface temperatures in Bay of Islands. Fig.1.10 shows the midsummer situation with waters in deeper parts of the bay up to 7.0°C . cooler than the surface, and the thermocline occurring at 10-20m. Fig.1.11 gives the early spring situation, with evidence of the thermocline developing in surface bay waters.

These transects suggest a thermocline developing in spring and early summer, probably with an inversion occurring during the winter.

Tidal currents are too great at the Confluence hydrological station for temperature stratification to develop.

Monthly changes in the subsurface temperatures at the four hydrological stations in Wellington harbour are given in Figs. 1.20, and 1.21. Observations were not made at the same stage of the tide, but the transects from Ngauranga to Eastbourne on ebb and flood tides in Fig. 1.26(c) suggest the basic water temperature structure remains the same. Temperatures ranged from 20.0°C . in late February to 11.0°C . in August, 1971. (Subsurface temperatures were 10.6°C . in June 1970). Other published subsurface temperature measurements for Wellington Harbour have been observations at 5m (R.M.Cassie, 1960) and at 10m (R.M.Cassie, 1959), and midwinter subsurface temperature profiles (Brodie, 1958). The first two make no comparisons between surface and subsurface values; Brodie (1958) showed $1^{\circ} - 2^{\circ}\text{F}$. difference between surface and bottom waters for the harbour on 26 May 1953. Surface and subsurface temperatures during 1970-71 varied by zero in autumn and spring to 2.0°C . in summer. Figs. 1.20 (B) and (C) and 1.21, and to a lesser extent 1.20 (A), show the development and movement of the thermocline from November to March. It is most characteristic of the deeper waters but also occurs in shallow waters off Petone Beach (Fig. 1.21). In late Winter 1970, the water was largely isothermal. In October and November the water at the surface warmed at a greater rate than that below, a thermocline developed at the surface (December, 1970) and moved downwards, disappearing by March, 1971. Autumn and winter conditions were largely isothermal, but with surface waters cooling faster than bottom waters. In November and December 1971 the thermocline redeveloped, with the water isothermal by February 1972.

There was no evidence of temperature differences of 4.0°C . between surface and subsurface values as noted by Skerman (1958) for Wellington Harbour, and the figure of 2°C . suggested by Maxwell (1956) more closely fits this data.

2. Salinity.

Factors affecting the salinity in any harbour include oceanic influences, freshwater inflow, precipitation and evaporation.

Near coast open water salinities off Bay of Islands are high (Fuller, 1953) and were within the $35.7^{\circ}/\text{oo}$ isohaline in February, 1955 (Garner, 1961). The width of Bay of Islands harbour entrance does not restrict high salinity water reaching well inland, and much of the harbour has salinities exceeding $35.5^{\circ}/\text{oo}$.

Salinity observations (Tables 1.4 and 1.5, and Figs. 1.9, 1.10 and 1.12) were too infrequent to relate salinity changes to rainfall, but minimum salinities occurred during winter and summer. Normal freshwater inflow causes small reductions in the salinity of the bay, and even values of $35.3^{\circ}/\text{oo}$ (only $0.4^{\circ}/\text{oo}$ less than near coast open water) were common at the estuarine Confluence hydrological station.

Few subsurface salinity observations were made (Table 1.6). Under normal freshwater inflow conditions, mixing is sufficient at the Confluence to stop salinity stratification. During flooding, surface salinities at the Confluence and Brampton Reef stations may drop to about $28^{\circ}/\text{oo}$ and a thin surface layer of fresh water may extend into the bay, but this is rapidly assimilated.

Wellington Harbour is topographically more constricted and prone to lowering of salinities by freshwater inflow. The influence of the Hutt River under normal and flood conditions has previously been discussed.

Hefford (1947) recorded Cook Strait salinities of $34.5 - 35.0^{\circ}/\text{oo}$, and this is consistent with more recent observations. For example, Garner (1953) recorded the $34.7 - 34.8^{\circ}/\text{oo}$ surface isohaline off the entrance to Wellington Harbour on 19/20 October 1950, and Heath (1971) recorded Cook Strait Canyon salinities ranging from 34.0 to $35.0^{\circ}/\text{oo}$ during 1968-69 (Table 1.16).

TABLE 1.16 COOK STRAIT CANYON SALINITIES (From Heath, 1971)

Date	Salinity (o/oo)	Date	Salinity(o/oo)
1/10/68	34.5	17/6/69	34.9
5/11/68	34.8	22/7/69	34.9
18/2/69	34.0	9/9/69	34.9
22/4/69	34.7	7/10/69	35.0

There is considerable variation in the range of surface salinities given in earlier studies for Wellington Harbour. Gilmour (1960b) recorded common salinity values of $34.4 - 35.2^{\circ}/\text{oo}$ for the west side of the harbour (Queen's Wharf). Maxwell (1956) recorded little variation in surface salinities at Queen's Wharf, with minimum and maximum salinities of $34.1^{\circ}/\text{oo}$ and $35.9^{\circ}/\text{oo}$ respectively. This author concluded that much of the harbour surface salinities were between 32.5 and $33.5^{\circ}/\text{oo}$. Maximum and minimum midwinter surface salinities of $33.86^{\circ}/\text{oo}$ and $22.28^{\circ}/\text{oo}$ were recorded by Brodie (1958). V.Cassie (1960) recorded maximum and minimum values of $34.9^{\circ}/\text{oo}$ and $29.0^{\circ}/\text{oo}$ for 1957-58. R.M.Cassie (1960) showed a drop in salinity at 5m of $0.8^{\circ}/\text{oo}$ from $35.1^{\circ}/\text{oo}$ at the harbour mouth to a station off Ward Island. Fig.1.23(B) shows a drop of $1.2^{\circ}/\text{oo}$ for the same transect on 26/7/71.

Surface salinities observed during 1970-71 are recorded in Tables 1.10 and 1.11, and Fig.1.26(B). The maximum value observed was $35.38^{\circ}/\text{oo}$ at South West Somes Island on 25/2/71, and the minimum $21.8^{\circ}/\text{oo}$ at Petone Beach on 7/10/71. Surface salinities at the four hydrological stations (Fig.1.16) under normal freshwater inflow ranged from $33.5 - 34.5^{\circ}/\text{oo}$, which is $0.5 - 1.5^{\circ}/\text{oo}$ below Cook Strait Canyon surface salinities. (Table 1.16) This harbour surface salinity range is approximately $1^{\circ}/\text{oo}$ less than that given by Gilmour (1960b) and $1^{\circ}/\text{oo}$ more than that given by Maxwell (1956).

Under flood conditions, salinities decrease to 25 - 30⁰/oo, with Petone Beach and Ngauranga hydrological stations (3 and 4) being most prone to freshwater dilution, but the central part of the harbour seldom falling below 30.0⁰/oo.

Salinity profiles are given in Figs. 1.24 and 1.25. In the main part of the harbour under normal freshwater inflow conditions, the salinity is fairly uniform in the vertical column (except in the cases of possible subterranean leakages and at points under the direct influence of the Hutt River), and surface salinities differ by up to 1.0⁰/oo from bottom salinities.

3. Dissolved Oxygen.

Bodies of highly stratified water with little mixing are most likely to undergo dissolved oxygen depletion. The degree of mixing observed at both harbours would generally preclude serious oxygen depletion.

There is no previous data on dissolved oxygen content from either harbour. The values observed during this study were close to or above 100% saturation in surface waters down to at least 8m, and never fell below 65% saturation at depths of 15m. (Tables 1.7 and 1.13). The data is insufficient to make seasonal variations evident, but there is little reason to expect values at any time of the year at any depth in the main parts of either harbour to fall below 50% oxygen saturation.

All observations were made during the day, so there is no evidence of diurnal variations in dissolved oxygen content of the type reported by Miyake (1948) and Park, Hood and Odum (1958). The inverse relationship between the solubility of oxygen and the seawater temperature (Truesdale, Downing and Lowden, 1955) has been accounted for in the calculations of percentage saturation.

4. Turbidity.

Factors affecting the amount of suspended material in any harbour include wind-mixing, tidal scouring and river discharge. Burt (1955) found local time changes, seasonal and tidal variations, and large

horizontal gradients of turbidity in Chesapeake Bay, North America. The effects of suspended materials, particularly erosion silt, are to reduce light penetration, influence heat radiation, and blanket the bottom (Ellis, 1936).

The value of the Secchi Disc (SD) has been widely discussed in literature. Postma (1961) concluded that it is useful in estimating relative amounts of suspended material. Poole and Atkins (1929) concluded that quite large variations in day brightness have little effect on the visibility of the Secchi Disc, although wind (sea surface ruffle) may make uniform readings difficult.

Inner parts of Bay of Islands have similar turbidity to much of Wellington Harbour, with SD visibility values of 3 - 6m. In these areas currents are maximal and sediments fine; Postma (1954 and 1961) observed a close relationship between current strength and silt content. In outer areas of Bay of Islands silt content is low, and SD visibility values often exceed 15m. Table 1.8 and Fig.1.13 summarise the observations. These are too infrequent to deduce seasonal variations, but maximal turbidity occurs during maximal river discharge, when bands of discoloured surface water may extend well into the bay.

The tidal surveys at the Confluence hydrological station under normal river discharge conditions showed little variation in turbidity during the tidal cycle, the station being too distant from the turbidity sources.

Phytoplankton blooms cause reduced SD visibility values at certain times of the year, particularly during spring. Hart (1962) and Atkins, Jenkins and Warren (1954) recorded phytoplankton quantity as a main factor affecting the visual range of the SD in the surface waters of some oceans.

Maxwell (1956) commented on pollution and turbidity in Wellington Harbour, concluding that shipping activity accounted for much of the turbidity. There has been no published turbidity values for Wellington Harbour, although V.Cassie (1960) gives the turbidity as "moderate - extreme". Brodie (1958)

detailed the movement of discoloured waters from the Hutt River and other streams in the harbour under varying wind conditions. He concluded that under north and northwest winds the Hutt River outflow is confined to a narrow zone down the eastern shore of the harbour, and in southerly winds the water lies as a thin surface layer across the northern end of the harbour.

Wellington Harbour SD visibility values during the sampling period varied from 2.25 - 6.5m (Table 1.14). Fig.1.27(B) shows much greater SD visibility values at the harbour entrance (13.5m), and the east-west transect (Fig.1.27(A) and (B)) show little variation in turbidity. Under flood conditions, Petone Beach and Ngauranga stations are most affected, and Mahanga Bay station the least affected by silt inflow.

Bary (1951, 1952 and 1956) discussed the discoloration of seawater by plankton in New Zealand waters, and showed the local distribution patterns of the ciliated protozoan Cyclotrichium meuneri under varying wind conditions in Wellington Harbour; Norris (1964) discussed the bloom of some phytoplankton organisms in the harbour, all of which affect SD values at certain times of the year.

Turbidity variations in the vertical column were not determined. Brodie (1958) reported the discoloured flood water under southerly winds to be a thin surface layer, which was rapidly assimilated, causing a slight general increase in harbour turbidity. The turbidity produced by shipping, discussed by Maxwell (1956), causes variations in the whole column. Plankton blooms generally remain concentrated in surface layers (Pomeroy, Haskin and Ragotzkie, 1956).

The observations are too brief to deduce seasonal variations, but again maximum turbidities occur at flooding, most commonly during winter.

Greatest variations during tidal cycles in SD visibility are expected in stations close to silt inflow (stations 3 and 4); the tidal surveys at Mahanga Bay nearer the harbour entrance showed little variation.

(C). CURRENTS IN BAY OF ISLANDS.

Factors affecting the currents in Bay of Islands include bottom topography, tides, coastal currents, runoff, differences in water density, and winds. The continental shelf slopes gently away north and south of Bay of Islands with Cape Brett, the most ~~eastern~~ point on the Northland peninsular, extending outwards to the 50 fathom ~~contour~~. The flood tide sets northwards on the east coast of Northland, rounds Cape Brett and moves westwards into the bay, while the tide ebbs eastwards along the southern shore of the bay. The East Australian current rounds North Cape and heads south ~~east~~ down Northland (Brodie, 1960) but Bay of Islands is probably most influenced by local eddy effects derived from this current. Winds affect the surface water layers in particular, but frictional effects produce a small net movement in the whole body of water. Net movements in the bay are caused mainly by the near coast open water current system, modified by the bottom topography, and wind, although increased runoff causes temporary changes in currents in confined estuarine areas. Tidal oscillations are largely repetitive and equal.

Much has been published on the production of surface currents by wind. Haines and Bryson (1961) call the ratio of water velocity to wind velocity the "wind factor" and found that water velocity in the surface layers increases with the wind velocity, until a critical wind speed is reached, and then decreases. They suggested an average wind factor of 1.31% for wind-driven currents in the upper 60cm. of water. Hughes (1956) concluded that water within 1 cm. of the surface drifts with 2.2% of the wind velocity and in the same direction. Under prolonged wind influence quite a large body of water may assume the prevailing wind direction. Ekman (in Tully, 1942) calculated that the steady state of wind-driven currents are attained in less than a day. Shulman and Bryson (1961) concluded that the depth of frictional influence lies between 2 and 3.5m. Large areas of the estuaries lie in this depth range, and are most prone to wind induced currents; the basin itself is far deeper, and wind

induced currents will overlay other currents. The use of drift drogues eliminates the effect of wind when determining subsurface currents.

Table 1.2 analyses the relationship between wind measurements at 0900 hours and 1300 hours at Waitangi Meteorological station. The observations at the two times of the day show sufficient similarity to allow the use of only the 0900 hours readings in connection with drift card releases. (Observations at 1300 hours were available for short periods only).

The value of drift cards in determining current systems in a confined harbour such as Bay of Islands is uncertain. Brodie (1960) discussed the use of drift cards. Their main advantage in this work over drift bottles is that they are unbreakable. Olson (1951) used them extensively and successfully on Lake Erie, and found that they often travelled independently of the prevailing or resultant wind. Wind induced currents in enclosed harbours are often important, and cards will respond to these. The induced current may however over-ride an opposing current lower in the water column.

86% of the drift cards released within Bay of Islands (Fig.1.14 A-E) were recovered along the southern shore, suggesting a net south to southeast movement of water. The two drift drogues, influenced by currents at 8M depth, moved due east (Fig.1.14F) while within the bay.

In winter, land drainage is maximal, NW winds predominate, (Fig.1.6C) and the cards drift mainly eastwards (Fig.1.14, A and B). In summer, land drainage is often minimal, north east or east winds predominate and drift cards move south or south east (Fig.1.14 C and D).

No attempt is made to assess current velocities from the drift card movements as the small local population often made recoveries slow. Redistribution of cards may have occurred, but it is assumed that the cards will redistribute with prevailing currents.

The release of drift cards at five stations off the coast in February 1972 (Fig.1.15) indicates a division of nearshore open water

surface currents by the Cape Brett peninsular. Cards released at Cape Brett (Station 4) moved either west into the bay, probably under the influence of the easterly wind, or south. Cards released south of Cape Brett (Station 5) moved south. Those released north of Cape Brett (Stations 1, 2 and 3) moved north, opposing the southerly wind element which occurred after the release of the cards (see Fig.1.15). The prevailing east wind element, typical of summer conditions, results in a west movement of cards and surface water. A possible local current system is shown in Fig.1.28. The drift card recoveries (Fig.1.14B and C), and the drift drogue recovery (Fig.1.14 F), made south of Bay of Islands from releases within the bay show a net water movement out of the bay southwards. The water must move along the southern shore of the bay to be picked up by the southerly coastal current shown in Fig.1.28. The drift card movements within the bay (mainly in the directions south to east) support this theory.

The recovery in Bay of Islands of two cards from Cape Brett (Station 4 in Fig.1.15) is hard to reconcile. In the first case, the card was recovered on 12/3/72 after a spell of Beaufort force 3 to 4 east and northeast winds, while in exactly the same period a card released from the same station was recovered at Whangamumu, 5 miles south of Cape Brett. In the second case, the card was not recovered for one and a half months, and may have been similarly affected.

The persistence of the offshore system is not verified, but correspondence with some local fishermen indicates two opposing currents throughout the year - a north moving eddy current off the mouth of the bay, consistent with these observations, and a south moving current 10-15 miles offshore, probably the East Australian current. There may well be a seasonal variation in the direction and speed of these currents, as reported elsewhere by Cooper, Lawford and Veley (1960), and Fuglister (1951).

The depth of the offshore surface current system is unknown. The temperature/salinity data in Fig.1.10 shows a defined mass of water extending to 40m at stations 6 and 8, (with slightly cooler, more saline

surface water) which does not occur further in at stations 5 and 10.

Greatest recoveries of cards within Bay of Islands were made during the summer months, when the human population was highest due to tourist influxes; much of the bay, particularly the outer areas, is deserted during the winter months. The release station near Cape Brett (Fig.1.14F) had the lowest overall recovery (17%), probably because of its isolation and the loss of cards south of Bay of Islands from it. The overall percentage recoveries from the other stations is high compared to several other New Zealand drift card studies.

CONCLUSIONS

Although some unique hydrological quantities are generated within both harbours, their localised distribution is temporary and they are rapidly assimilated. Relatively little vertical stratification of any hydrological parameter was observed in the main basins of either harbour, except the development of a summer thermocline particularly in Bay of Islands. Both harbours are therefore quite well mixed.

The main differences between the two harbours lie in the extent of their oceanic contact, and the extent of the area of regression between oceanic and harbour conditions. Wellington harbour is probably more clearly cut off from Cook Strait than suggested by some authors.

Assuming the availability of suitable substrates, it is unlikely that the hydrological regime at either harbour would preclude the occurrence of any species, except those which approach the limit of their water temperature tolerance. The homogeneity of the water will cause rapid mixing of plankton after localised outbursts of spawnings.

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SECTION 2

OBSERVATIONS ON THE BIVALVE FAUNA

OF

BAY OF ISLANDS

AND

WELLINGTON HARBOUR,

NEW ZEALAND

SUMMARY

Benthic and shore collections of marine bivalve molluscs were made in Bay of Islands, and benthic collections were made in Wellington Harbour, during 1970-72. The species occurring are recorded and discussed, and the distribution of some common species in Wellington Harbour is related to sediment types.

A list of bivalve molluscs collected in Bay of Islands is presented, and additional species to previous Wellington Harbour species lists are recorded.

Invertebrate marine communities described for New Zealand are discussed, and the bivalve fauna of both harbours is visually compared to these communities. The observations at fiftyfour anchor dredge benthic stations in Wellington Harbour are then treated statistically, and compared to the visual assessments. It appears that the great variability in Wellington Harbour sediments makes identity of classical communities in the harbour almost impossible. However, station groups (groups of stations with similar bivalve species present) are evident, and their distribution in Wellington Harbour correlates closely to sediment type distribution.

Lists of the most abundant bivalve species occurring in both harbours, deduced from all the observations presented in this study, are given.

INTRODUCTION

Bay of Islands is an embayment of approximately fifty square miles on the east coast of Northland (latitude 35°S), and Wellington Harbour of thirty square miles, lies 6° latitude further south on the southern coast of the North Island. (See Fig.1.1). The physiography and hydrology of the harbours has been discussed in Section 1. Knox (1963) placed Bay of Islands in the Aupourian Province, with a transitional warm temperate climate (mean sea temperature range of $12^{\circ} - 20^{\circ}\text{C.}$), and

Wellington harbour in the Cookian Province, with a cold temperate climate and a mean sea temperature range of 7° - 18°C . Dell (1962), however, questioned the reality of marine provinces in New Zealand.

Knox (1963) discussed the general intertidal ecology of the northern and central regions of New Zealand, and Morton and Miller (1968) discussed the littoral and sublittoral ecology of typical harbours in these areas. McKnight (1969) summarised the several New Zealand studies on the associations of benthic invertebrates, while Hefford (1947) and Yaldwyn (1957) reviewed deepwater biological investigations in New Zealand, including some in these areas.

No comprehensive account of the molluscan fauna of Bay of Islands has been published. Powell (1936 and 1940) listed marine molluscs from the Auporian province, which he defined as being Whangaroa-Ahipara northwards. Cooper (1898) listed molluscs collected from Whangarei Heads, 30 miles south of Bay of Islands; Powell (1927) gave those taken at 23 fathoms off Ahipara, 30 miles north of Bay of Islands on the West Coast; Mestayer (1916) listed those from dredgings in the North Cape area. Morton and Miller (1968) made ecological observations on the invertebrate fauna of Northland, and included some examples from Bay of Islands. McKnight (1969) referred to invertebrate collections off Northland east coast areas. Other papers gave new species obtained in deep-water outside the bay (Powell, 1929 and 1930, Mestayer, 1930, Dell, 1963 etc.)

Some studies on particular bivalve species have been made in Bay of Islands. Elliott (1966) and Dinamani (1971) described aspects of the biology of Crassostrea glomerata in the bay. Booth (1969) described some shore collections of bivalve molluscs. Other collections by amateur conchologists remain unpublished, and I draw upon some of these for this paper.

Fell (1960) described in general terms the marine shallow water fauna of Wellington Harbour. Beu and Climo (1971) presented a revised list of the molluscan fauna of the harbour, and referred to earlier species lists for the area. (Kirk, 1879, and Iredale and Mastayer, 1907). Other recent

mulloscan studies in the harbour have included those of Ponder (1965), Wear (1966), Fless (1968) and McKay (1970).

There have been few intensive quantitative studies on the living marine benthic fauna of New Zealand. The main quantitative studies referred to in this paper include those of Powell (1937), Hurley (1964), Paul (1966), Estcourt (1967), Wood (1968), and McKnight (1968 and 1969).

METHODS

Faunal samples were obtained by five main methods:

1. Petersen grab in water greater than 10m deep in Bay of Islands.
2. Sledge dredge in water 1m - 10m deep, mainly in Bay of Islands.
3. Shore collections of living upper sublittoral and midlittoral species and dead cast-up shells in midlittoral and supra-littoral zones in Bay of Islands.
4. Anchor dredge in Wellington Harbour.
5. Agassiz trawl in Wellington Harbour.

Petersen grab samples ($0.063m^2$) were collected in Bay of Islands on 15/9/71 from m.v. "Ikateri", packed in large plastic bags, and sieved in the laboratory through ^{1mm} mesh, and the live and dead bivalves recorded. The Petersen grab is described and its efficiency discussed by Orton (1925). Kutty and Desai (1968) list several workers who found the Petersen-type grab less efficient than others (including the Van Veen). In this survey the grab was inefficient, generally yielding a small bottom sample. The approximate weight of benthic material retrieved is given with each

station in Table 2.1, but obviously substrates such as sand would filter through gaps in the grab as it was being winched up.

The sledge dredge consisted of a 1 x 0.5 m flat steel plate with a turned up bow and a cutting edge one third back which scraped substrate into a wire mesh basket (1 cm. diameter mesh) mounted on the plate. Samples were collected in Bay of Islands between May 1970 and December 1971 from a 19 foot outboard launch. The dredge can be operated by one person, and its shape allows it to be planed to the surface where it quickly filters substrate material.

Shore collections of living and cast-up bivalves were made in Bay of Islands mainly in January, 1972.

Anchor dredge collections were made in Wellington Harbour on 18/2/72, 21/2/72 and 26/4/72 from M.V. "Tirohia", and hosed and sieved at sea with 6mm and 3mm meshes. Living bivalves only were recorded. Forster (1953) described the anchor dredge. The one used in this study, with a mouth 45.8cm. x 28 cm., gave a bottom scoop of approximately 46.7 litres. In most cases the anchor dredge filled on the first haul; if not, the dredge was emptied and the station resampled. The dredge completely and immediately filled when sampling on most substrates and once full dragged along with virtually no addition to its contents. Substrates sampled in Wellington Harbour were quite compact, and in all but the finest sand, the dredge was hauled aboard completely full. Underwater observations showed the dredge to dig approximately 9 cm. into both muddy and sandy substrates (B. Godfriaux - pers. comm.) This dredge yielded the most valuable quantitative results of all methods used.

Agassiz trawls of 3-5 minute duration were made in Wellington Harbour on 27/3/72 and 30/3/72 from M.V. "Tirohia" and sorted at sea. The trawl used was 1.6 metres wide with a square 2.5 cm. (side) mesh, and it seldom showed any sign of having penetrated the substrate. Living bivalves only were recorded.

SPECIES NAMES

The identification of bivalves collected during this study were confirmed by Dr.F.Climo, Dominion Museum, Wellington. The source of identification in other bivalve collections referred to is given with the collection list.

Species are named following the revised list of molluscs from Wellington Harbour given by Beu and Climo (1971). In bivalve species which do not occur in this list, species names are taken from Powell (1961).

Species authors are not recorded. These can be obtained from Powell (1961) and Beu and Climo (1971).

SAMPLING AREAS AND STATIONS

The main physiographic features and town locations for Bay of Islands have been given in Figs. 1.2, 1.3 and 1.4, and those for Wellington Harbour in Fig.1.16. Frequent reference will be made to these.

The Bay of Islands shore and benthic stations are given in Fig.2.1 and Table 2.1. The Wellington Harbour benthic stations are given in Fig.2.2 and Tables 2.2 and 2.3.

RESULTS

The bivalve species (live and dead) obtained in the Petersen grab and sledge dredge surveys in Bay of Islands are given in Table 2.4. The dates of the collections are given in each table. Table 2.5 gives the occurrence of some bivalve species from Bay of Islands, including those from the shore and benthic collections, and includes the source of the data.

Bivalve species occurring live in the anchor dredge surveys in Wellington Harbour are given in Table 2.6, and from the Agassiz trawl surveys in Table 2.7. Species occurring in Wellington Harbour, but not listed by Beu and Climo (1971), are Offadesma angasi (at Stations 15 and 16 in

Fig.2.2) and Diplodonta zelandica (at Station 26 in Fig.2.2).

The distribution of some of the more abundant bivalve species in Wellington Harbour, derived from the anchor dredge surveys, is given in Fig.2.3

Other bivalve collections made in the harbour during 1970-72 are given in Table.2.8. Also given are the date and method of sampling, as well as the station from Fig.2.2 that most closely fits the site.

FIG. 2.1

BAY OF ISLANDS

Sublittoral and shore stations.

A - sublittoral station

B - shore station.

See also Table 2.1

FIG. 2.2

WELLINGTON HARBOUR

Sublittoral stations.

The **contours** are for grain size distribution,
from Van der Linden (1967), (see Fig. 2.5)

See also Table 2.2

FIG. 1

FIG. 2

A. SUBLITTORAL STATIONS

Stations A1 - A16 sampled with Petersen Grab on 15/9/71

Stations A17 - A19 sampled with sledge dredge in January, 1971

Station No.	Latitude S	Longitude E	Depth m	Substrate Type	Weight Retrieved (gms)
A1	35°14'	174°7'	23	sand	40
A2	12'	8'	38	mud	225
A3	11'	7'	30	shell/sand	1600
A4	11'	10'	53	mud	1125
A5	9.5'	8.5'	45	mud	160
A6	9'	9'	58	fine gravel	325
A7	9'	12'	87	mud	400
A8	9'	5'	87	mud	250
A9	9.5'	20'	95	mud	1250
A10	10.5'	6.5'	77	mud	2250
A11	11.5'	12.5'	53	shell/sand	225
A12	13'	10'	32	fine gravel	44
A13	14'	9'	30	sand	1000
A14	14'	8'	28	sand	1375
A15	14'	6'	21	sand/mud	3175
A16	15'	6'	14	shell/sand	1250
A17	2.25'	12.5'	2	sand	-
A18	2.25'	3'	2	shell	-
A19	1.75'	3.5'	9	mud	-

B SHORE STATIONS

Collections made in January, 1972

STATION	LOCALITY	LATITUDE S	LONGITUDE E
B1	WAIROA BAY	35° 15.5'	174° 4.25'
B2	ENGLISH BAY	18.5'	6'
B3	PAREKURA BAY	15.5'	14.5'
B4	RAWHITI	14'	15.5'
B5	OKE BAY	14'	15.75'
B6	WAEWAETORIA	12.25'	12.5'
B7	WHALE BAY	10.5'	6.5'
B8	TE PAHI ISLANDS	10.5'	5.75'
B9	TE PUNA INLET	11'	3'
B10	KERIKERI INLET	12'	2'
B11	WAIREKA	12.75'	3.5'
B12	KENT PASSAGE	13.25'	4'

TABLE 2.2 WELLINGTON HARBOUR SUBLITTORAL STATIONS-
ANCHOR DREDGE

81.

STATIONS 1-20 sampled on 18/2/72, 21-30 on 21/2/72
and 31-54 on 26/4/72.

Station No.	Lat. S	Long. E	Depth m	Station No.	Lat. S.	Long. E	Depth m
1	47° 17'	174° 47.4'	17	28	47° 20'	174° 51.5'	5
2	16'	47.4'	15	29	18'	48.6'	18
3	15'	49'	18	30	18.9'	48.3'	13
4	14'	50.6'	9	31	14.5'	50'	17
5	14'	51.5'	9	32	14.5'	51.6'	16
6	14'	53'	1.5	33	14.6'	53.1'	13
7	15'	54.2'	1.5	34	15.5'	47.9'	16
8	15'	53'	16	35	15.5'	48.6'	21
9	15'	51.5'	20	36	15.5'	50'	21
10	15'	50'	19	37	15.5'	51.5'	20
11	16'	48.6'	20	38	15.5'	53'	19
12	16'	50'	22	39	15.5'	54.5'	4
13	16'	51.5'	23	40	16.5'	47.4'	12
14	16'	53'	20	41	16.5'	48.6'	20
15	16'	54.2'	7	42	16.5'	50'	22
16	17'	54.1'	4	43	16.5'	51.5'	22
17	17'	53'	20	44	16.5'	53'	21
18	17'	51.5'	22	45	16.5'	54.2'	11
19	17'	50'	22	46	17.4'	47.4'	13
20	17'	48.6'	19	47	17.5'	48.6'	18
21	18'	50.1'	3	48	17.5'	50.1'	4
22	18'	51.5'	12	49	17.5'	51.5'	16
23	18'	53'	3	50	17.5'	53'	16
24	19'	52.6'	2	51	18.5'	50'	5
25	19'	51.5'	8	52	18.5'	51.5'	11
26	19'	50'	9	53	18.5'	53'	3
27	20'	50.5'	5	54	18.4'	48.6'	17

TABLE 2.3

WELLINGTON HARBOUR SUBLITTORAL STATIONS

AGASSIZ TRAWL

Station locations same as in Table 2.2 and Fig.2.2

Station No.	Sampling Date	Station No.	Sampling Date
1	30/3/72	20	30/3/72
5	27/3/72	21	27/3/72
8	27/3/72	22	27/3/72
10	30/3/72	23	27/3/72
11	30/3/72	24	27/3/72
12	30/3/72	25	27/3/72
13	27/3/72	26	27/3/72
15	27/3/72	27	27/3/72
16	27/3/72	28	27/3/72
18	27/3/72	29	30/3/72

TABLE 2.4.

BAY OF ISLANDS

Bivalve species (live and dead) obtained in the Petersen grab and sledge dredge surveys.

Stations A1 - A16 were sampled with the Petersen grab on 15/9/71.

Stations A17 - A19 were sampled with the sledge dredge during January 1971.

Some stations yielded no bivalves.

Bivalves occurring as dead valves are bracketed.

In stations A17 - A19, a dash records the species as being present.

For station positions, see Fig.2.1 and Table 2.1.

TABLE 2.5

SOME BAY OF ISLANDS BIVALVE MOLLUSCS

A - denotes sublittoral station numbers (See Table 2.1)

B - denotes shore station number (Table 2.1)

Identifications verified by Dr. F. Climo, Dominion Museum.

LS - Species recorded from Bay of Islands by Mrs. L. Seager, Opua, Bay of Islands. Samples obtained by shore collecting and dredging with hand-operated naturalist dredge. Identifications by Mrs. Seager, Dr. A.W.B. Powell, Auckland Museum, and Dr. F. Climo.

JH - Species recorded from Bay of Islands by Mr. J. Hancock, Kamo. Samples obtained by shore collecting and dredging. Identifications by Mr. Hancock and Dr. F. Climo.

Species	Source
<i>Solemya parkinsoni</i>	LS, B1-2, B11-12
<i>Nucula hartvigiana</i>	LS, MH, A17-18, B1-4, B6, B9, B10-12
<i>Nucula nitidula</i>	LS, A2-4, A10, A13, A14
(<i>Ennucula</i>) <i>strangei</i>	MH
<i>Nuculana bellula</i>	LS, MH, A2, A4, A7, A10
<i>Nuculana hedleyi</i>	MH
<i>Poroleuca lanceolata</i>	LS, MH, A2, A10
<i>Neilo australis</i>	LS, MH, A2, A4, A10
<i>Barbatia novaezealandiae</i>	LS, MH, B1, B6-8, B11-12
<i>Acar sandersonae</i>	LS, MH, A2
<i>Bathyarca cybaea</i>	LS, MH
<i>Glycymeris laticostata</i>	LS, MH, A17-18, B4, B6, B8, B11-12
(<i>Glycymerula</i>) <i>modesta</i>	LS, MH, A3, A11, A16-18, B6-8, B11-12
<i>Hochstetteria munita</i>	LS, MH
<i>Cosa costata</i>	MH
<i>Cosa serratocostata</i>	MH
<i>Mytilus edulis aoteanus</i>	LS, MH, A3, B1-6, B8-12
<i>Perna canaliculus</i>	LS, MH, B1-3, B8, B11-12
<i>Aulacomya maoriana</i>	LS, MH, B1
<i>Modiolus areolatus</i>	LS, MH, B7-8, B11-12
<i>Xenostrobus securis</i>	B10
<i>Xenostrobus pulex</i>	LS, MH, B1-5, B8-12
<i>Septifer</i> cf. <i>bilocularis</i>	LS
<i>Modiolarca impacta</i>	LS, MH, A18, B1-4, B6-8, B11-12
<i>Gregariella barbata</i>	LS, B1
<i>Zelithophaga truncata</i>	LS, MH, B12
<i>Crenella radians</i>	LS

Species	Source
<i>Atrina pectinata zelandica</i>	LS, B1-4, B6, B8, B10-12
<i>Pecten novaezelandiae</i>	LS, MH, A18, B1-4, B6-8, B10-12
<i>Chlamys</i> (Mim) <i>zelandona</i>	MH
<i>Chlamys</i> (Mim) <i>zelandiae</i>	LS, MH, A13-15, A18, B1-4, B6-8, B11-12
(<i>Mesopeplum</i>) <i>convexum</i>	MH
<i>Limatula maoria</i>	LS, MH, A3, A10
<i>Divarilima sydneyensis</i>	LS
<i>Anomia walteri</i>	LS, MH, B1-4, B7-8, B10-12
<i>Ostrea charlottae</i>	LS
<i>Ostrea angasi</i>	LS
<i>Ostrea</i> Sp.	B1-12
<i>Crassostrea glomerata</i>	LS, MH, B1-12
<i>Talabrica bellula</i>	LS, MH
<i>Cuna aupouria</i>	LS, MH
<i>Cuna manawatawhia</i>	LS
<i>Cuna mayi</i>	LS
<i>Cuna waikukuensis</i>	LS
<i>Cuna gibbosa</i>	LS
<i>Cardita aoteana</i>	LS, MH
<i>Cardita brookesi</i>	LS, MH, B12
<i>Venericardia purpurata</i>	LS, MH, A17-18, B11-12
<i>Pleuromeris zelandica</i>	LS, MH, A2, A14-15, B6, B8, B12
<i>Neogaimardia finlayi</i>	MH
<i>Diplodonta zelandica</i>	LS, MH, A14, B8, B11-12
<i>Diplodonta globus</i>	LS, MH, B1
<i>Diplodonta striatula</i>	LS, MH
<i>Thyasira peroniana</i>	MH
<i>Gonimyrtia concinna</i>	LS, B7
<i>Divaricella huttoniana</i>	LS, MH, A14, B6
<i>Lasaea maoria</i>	B7, B3-5, B9
<i>Lasaea rubra</i>	LS, B1, B3-4, B6, B8-12
<i>Kellia cycladiformis</i>	LS, B1
<i>Arthritica bifurca</i>	LS, B1-5, B7, B10-12
<i>Arthritica crassiformis</i>	B1, B3, B9
<i>Melliteryx parva</i>	MH
<i>Myllita stowei</i>	LS, MH, B8, B12
<i>Notolepton sanguineum</i>	LS, B1
<i>Notolepton antipodum</i>	MH
<i>Borniola reniformis</i>	LS, A4, A14, A17-18, B1, B3-4, B6-12
<i>Scintillona zelandicus</i>	LS, A2
<i>Nemocardium pulchellum</i>	LS, MH, A2, A4, A10, A14-15

Species	Source
<i>Dosinia lambata</i>	LS, A1, A14, A19
<i>Dosinia subrosea</i>	LS, B8
<i>Dosinia greyi</i>	LS
<i>Notocallista multistriata</i>	LS, MH, A4, A10
<i>Dosina crebra</i>	LS
<i>Dosina zelandica</i>	LS, MH, B8-9, B11-12
<i>Tawera spissa</i>	LS, MH, A3, A10, A13-14, A17-18, B4 B6-8, B11-12
<i>Bassina yatei</i>	LS, MH, B1, B8, B12
<i>Chione stutchburyi</i>	LS, MH, A3, B1-4, B8-12
<i>Irus elegans</i>	LS, MH, B9
<i>Protothaca crassicosta</i>	LS, MH, B1, B3-4, B8-12
<i>Venerupis largillierti</i>	LS, MH, B1, B3-4, B7-12
<i>Irus reflexus</i>	LS, B8-10, B12
<i>Tellinella charlottae</i>	LS, MH
<i>Tellinella huttoni</i>	LS, MH, A1
<i>Homalina gaimardi</i>	LS, MH, B8
<i>Angulus spenceri</i>	LS
<i>Tellinota edgari</i>	MH, B12
<i>Macomona liliana</i>	LS, MH, A1, A4, B1-4, B8-12
<i>Arcopagia disculus</i>	LS, MH, B7-8, B11
<i>Leptomya retiaria</i>	LS, MH, A18, B1, B8, B12
<i>Gari lineolata</i>	LS, MH, A3-4, A14-15, B8, B11-12
<i>Gari stangeri</i>	LS, MH, A14, B3, B5, B6-8, B11-12
<i>Soletellina nitida</i>	LS, MH
<i>Soletellina siliqua</i>	LS, MH, B1, B8
<i>Cyclomactra ovata</i>	LS, MH, B1-3, B9-10, B12
<i>Longimactra elongata</i>	LS, MH, A18, B8, B12
<i>Maorimactra ordinaria</i>	LS, A15
<i>Scalpomactra scalpellum</i>	LS, MH, A3-4, A10, A13-15
<i>Zenatia acinaces</i>	LS, MH, B5
<i>Resania lanceolata</i>	LS
<i>Paphies subtriangulatum</i>	LS, MH, B1, B4-6, B8
<i>Paphies australe</i>	LS, MH, B1-4, B8-12
<i>Hiatella australis</i>	LS, MH, A13, A16, B1, B3, B7
<i>Panopea zelandica</i>	LS, B8, B11
<i>Caryocorbula zelandica</i>	LS, MH, A3, A10, A16-18, B6-8, B11-12

Species	Source
<i>Barnea similis</i>	LS, MH, B1, B3, B8-9
<i>Bankia australis</i>	McQuire (1964), B1
<i>Lyrodus medilobata</i>	McQuire (1964)
<i>Myadora antipoda</i>	LS
<i>Myadora boltoni</i>	LS, MH, A13-14
<i>Myadora novaezelandiae</i>	LS, MH
<i>Myadora striata</i>	LS, MH, A3, B1, B8
<i>Myadora subrostrata</i>	LS, A6, A10
<i>Hunkydora australica</i>	LS, MH
<i>Cleidothera maorianus</i>	LS, B8
<i>Thracia vitrea</i>	LS, MH
<i>Offadesma angasi</i>	LS
<i>Haliris setosa</i>	LS
<i>Cuspidaria fairchildi</i>	MH
<i>Cuspidaria trailli</i>	LS, MH, A2, A4, A10
<i>Austroneaera brevirostris</i>	LS

TABLE 2.6

WELLINGTON HARBOUR

Anchor dredge surveys 18/2/71, 21/2/72, and 26/4/72.

Only live bivalves are recorded; some stations yielded no bivalves.

Station positions are given in Table 2.2 and Fig.2.2.

TABLE 2.7

WELLINGTON HARBOUR AGASSIZ TRAWL SURVEYS 27/3/72 and 30/3/72

Live bivalves only. Some stations yielded no bivalves.
Station positions are given in Fig 2.2.

SPECIES	1	5	8	10	11	12	13	15	16	18	20	21	22	23	24	25	26	27	28	29
<i>Perna canaliculus</i>								3	3			1	3		17		3		1	
<i>Aulacomya maoriana</i>									2											
<i>Modiolarca impacta</i>		3						237			1	14	6				5		1	
<i>Atrina pectinata zelandica</i>										1							18			
<i>Pecten novaezelandiae</i>											1									
<i>Chlamys (Mim) zelandiae</i>								7		2	3		7				11			3
<i>Monia zelandica</i>																	4			
<i>Ostrea lutaria</i>							4	4	2	4	1						1			4
<i>Nemocardium pulchellum</i>								1												
<i>Dosinia greyi</i>					3					1										1
<i>Dosina zelandica</i>								1												
<i>Venerupis largillierti</i>								3												
<i>Leptomya retiaria</i>				1				4												
<i>Caryocorbula zelandica</i>			2					18					1							
<i>Thracia vitrea</i>								3												

FIG. 2.3

WELLINGTON HARBOUR

Distribution of some common bivalve species in
Wellington Harbour (from Anchor Dredge Surveys)

Each circle gives the occurrence of one or
more animals.

FIG. 3

TABLE 2.8

WELLINGTON HARBOUR

OTHER BENTHIC BIVALVE COLLECTIONS

Live bivalves only

The station number given is that from Fig. 2.2 which most closely fits the site.

Date	Sampler	Species Present	Number	Station
8/12/70	Anchor D	<i>Ostrea lutaria</i>	2)	30
		<i>Atrina pectinata zelandica</i>	1)	
23/2/71	Orange peel	<i>Neilo australis</i>	2	2
2/9/71	Anchor D	<i>Myadora striata</i>	2	26
27/3/72	Sledge D	<i>Angulus edgari</i>	1)	5
		<i>Chione stutchburyi</i>	1)	
		<i>Dosinia lambata</i>	1)	
		<i>Modiolarca impacta</i>	1)	8
		<i>Dosinia lambata</i>	1)	
		<i>Dosinia greyi</i>	1)	
		<i>Angulus edgari</i>	1)	
		<i>Dosinia greyi</i>	1	13
		<i>Caryocorbula zelandica</i>	18)	15
		<i>Neilo australis</i>	1)	
		<i>Modiolarca impacta</i>	1)	
		<i>Leptomya retiaria</i>	1)	
		<i>Atrina pectinata zelandica</i>	1)	
		<i>Neilo australis</i>	1	16
		<i>Angulus edgari</i>	1)	18
		(<i>Ennucula</i>) <i>strangei</i>	1)	
		<i>Caryocorbula zelandica</i>	8	21
		<i>Myadora striata</i>	40)	23
		<i>Perna canaliculus</i>	1)	
		<i>Myadora striata</i>	1	25
		<i>Ostrea lutaria</i>	2)	26
		<i>Pecten novaezelandiae</i>	1)	
		<i>Thracia vitrea</i>	1)	
		<i>Dosinia lambata</i>	1)	
		<i>Gari lineolata</i>	2)	
		<i>Angulus edgari</i>	1)	

INTERPRETATION OF RESULTS AND DISCUSSION

GENERAL ANALYSIS OF RESULTS.

The wide range of substrates, salinities and exposure in both harbours, with conditions ranging from very low salinities (approximately 3⁰/oo) and protected shores in the estuaries to high salinities (34.5 - 36.0⁰/oo) and very exposed shores in outer areas, make the bivalve fauna of both harbours diverse. One hundred and twentyone species are recorded from Bay of Islands, and one hundred and eighteen from Wellington Harbour.

In both harbours few species are widespread. The widespread species in Bay of Islands generally are different from those in Wellington Harbour. Species that are abundant or common in Bay of Islands (although not necessarily widespread) are also often abundant or common ⁱⁿ Wellington Harbour (Tables 2.9 and 2.10) Crassostrea glomerata, the Northern rock oyster, and Dosinia greyi are obvious exceptions.

The maximum number of bivalve species at any one station in the Wellington Harbour anchor dredge survey was ten (station 48) in Fig.2.2, and the minimum 0. Fig. 2.4 shows faunistically rich, medium and poor regions in Wellington Harbour, and Fig.2.5 gives Wellington harbour sediments (from Van der Linden, 1967). Coarseness of sediments and tidal scouring make stations near the harbour entrance faunistically poor. The sand and sandy pelite substrates around Ward Island, along the eastern and northern margins and pockets on the western and southern margins of the harbour are apparently suitable substrates for many bivalve species. The silty pelite extending throughout much of the central region is suitable for few species. Only a few species are restricted by water depth to particular areas of the harbour. For example Chione stutchburyi and Paphies australe occur commonly in the sandy and very sandy pelite in the shallow water off Petone Beach only.

The benthic sampling in Bay of Islands was too incomplete and the Petersen grab too inefficient to make possible the determination of the distribution of faunistically rich and poor regions in the bay. Furthermore,

sediment analysis of Bay of Islands is restricted to a few observations.

FIGURE 2.4

WELLINGTON HARBOUR

Distribution of faunistically rich (5-10 species), medium (2 - 4 species) and poor (0 - 1 species) stations.

FIGURE 2.5

WELLINGTON HARBOUR

Grain size distribution (from Van der Linden, 1967).

FIG. 4

FIG. 5

marine benthic communities and associations. Stephenson, Williams and Lance (1970) and Stephenson and Williams (1971) reviewed the development of community concepts. The initial community concept was based on dominance, but it could not be satisfactorily applied to warmer waters, so giving rise to a school that stressed the independent distribution of species and ecological continuity. A more recent school is based on associations of species characterised by constant and faithful species, but it is merged with the non-community concept, and is statistical in its treatment of data. For example, Stephenson et al (1970) found species distributions that could not by inspection be classified into group patterns. But after objective computerization, "site-groups" (= station groups), not uniquely defined by the presence of a "species-group" that occurred nowhere else, became apparent; the differences between site-groups were quantitative, although often small.

More recently, Stephenson, Williams & Cook (1972) have attempted to identify objectively the so-called "well defined benthic communities" of the earlier classical studies overseas (e.g. Petersen, 1914). They concluded that in many areas, particularly in warmer waters, Petersen-type communities cannot be recognised.

Benthic community studies in New Zealand have been based largely on dominance, convenient because data becomes easily comparable on a visual level and no arduous analysis is required (in earlier studies, no computer analyses were available). Furthermore in many cases the intensity of the benthic study was insufficient to warrant detailed objective analysis.

The benthic data from the study in Bay of Islands is insufficient to be dealt with statistically. Sublittoral stations yielded few live bivalves, and dead shells as indicators of living bivalve populations must be used with caution, although Morton & Miller (1968) suggested "freshly cast-up beach shells give a good impression of the diversity of bivalves in shallow tidal regions". Similarly dredgings of dead shells can be used as indicators of living benthic populations of those species. The predominance of dead shells in the Petersen grab samples (Table 2.4) is striking;

77% of all species occurred as dead valves only. Macomona liliana was the only species occurring live more than once. Estcourt (1967) at Marlborough Sounds and Hurley (1964) at Milford Sound recorded similar situations, with dead shells and dead species outnumbering living ones. The absence of many live specimens in Bay of Islands is due mainly to the poor and shallow sample obtained with the Petersen grab. Estcourt (1967) concluded that in Marlborough Sounds all species occur live over the range of occurrence of their dead shells. The situation is probably similar in Bay of Islands, allowing discussion of possible species groups from the combined dead and living shell data.

The Wellington Harbour anchor dredge data are sufficient to be treated statistically. This is done in a later section. But the Bay of Islands and Wellington Harbour observations are firstly compared visually to communities and associations (real or not) which have already been described for New Zealand. The objective statistical analysis of the Wellington Harbour data is then compared with these visual assessments.

NEW ZEALAND COMMUNITIES.

Several communities (associations, assemblages) have been described in New Zealand, most commonly fitting the definition by Sanders (1960): "a group of species that show a high degree of association by tending to reo-occur together". Although many communities include non-molluscan invertebrates, bivalve molluscs are often the important species for the tagging of community types, making the present surveys indicative of the presence of community-types.

Hall (1964) suggested that the number of consecutive days or months on which shallow seawater was at the required temperature for reproduction and early growth of a mollusc species to take place was a critical factor in determining the survival of the species. He postulated the presence of six world marine climates, each characterising a molluscan province. Bay of Islands is in the warm temperate zone where species live in water at about

15⁰ - 18⁰C. for almost four consecutive months of the year and in water no colder than 10⁰C for the rest of the year (= transitional warm temperate climate of Knox, 1963). Wellington Harbour most closely fits the mild temperate province with temperatures not exceeding 15⁰C for three to four months, and then falling to approximately 10⁰C. for about 6 months (= cold temperate climate of Knox, 1963). The differences between these temperatures for Bay of Islands and Wellington Harbour are insufficient to exclude many species from either locality.

Spärck(1935) also arranged benthic communities initially according to latitudinal distribution (water temperature zones), and then according to substrate types. Thorson (1955), Jones (1956) etc. also emphasised substratetype as the most essential single factor influencing the composition of bottom communities.

The bivalve fauna of Bay of Islands and Wellington Harbour is now discussed according to the classification of Spärck(1935) for marine bottom communities.

1. Level Bottom Communities.

(a) Shallow water communities. Ralph and Yaldwyn (1956), Grace (1966) and Morton and Miller (1968) described the typical estuarine mudflat associations dominated by Chione stutchburyi, and often with Nucula hartvigiana. The Chione-Nucula - polyclaete association described by Grace (1966) for Whangateau Harbour occurs commonly in the extensive Bay of Islands estuaries (Fig.2.1, Stations B2, B9 and B 10. Also see Fig.1.6) and also on sheltered muddy embayments such as Wairoa Bay (B1) and Parekura Bay (B3). In Wellington Harbour it occurs in a restricted area around the mouth of the Hutt River, and on parts of Petone Beach (Fig.2.2, Stations 5, 6 and 7). Morton & Miller (1968) described additional species Macomona liliana and Cyclomactra ovata, which occur in both harbours, and correspond with community 2 of Wood (1968) at Howick Beach in the Hauraki Gulf. The small Leptonacean bivalve Arthritica bifurca occurs abundantly and free living in Bay of Islands estuaries, as noted by Ponder (1965) in

Auckland Harbour. Wear (1966) recorded its commensal relationship with the tubeworm Pectinaria australis on Petone Beach in Wellington Harbour. Although Pectinaria australis occurs in the estuaries in Bay of Islands, I did not encounter Arthritica bifurca commensal with it. Chione stutchburyi occurs in high densities in both harbours with the species in some of the Bay of Islands estuaries subject to periodic mass mortality. Local residents report a drastic reduction in live Chione stutchburyi in the Kerikeri estuary (Figs 1.2, and 2.6) during 1969-70. Mass mortality in bivalve populations is not uncommon, and is due mainly to disease, overpopulation or severe environmental conditions (e.g. Hancock & Urquhart, 1964 in the U.K.) Subsequently, I have noticed a large re-establishment of this species in the estuary. Orton (1937) and Coe (1953) described similar resurgent bivalve populations taking place in the United Kingdom and California respectively.

Fig. 2.6 gives the distribution of some bivalves in the Kerikeri Inlet in Bay of Islands. Chione stutchburyi penetrates well towards the freshwater source, occurring with the small brackish water mussel Xenostrobus securis. Paphies australe, which usually occurs in more open sea situations, extends almost as far towards the river mouth, but individuals have stunted growth and stained valves. Arthritica bifurca and Nucula hartvigiana have quite wide salinity tolerances and are common in the estuary, although the density of Nucula hartvigiana in no part of the Kerikeri Inlet reaches the densities reported in other estuaries in New Zealand by Morton & Miller (1968). In more saline conditions in the Kerikeri estuary Chione stutchburyi and Paphies australe occur together, or else Paphies australe replaces Chione stutchburyi. This then corresponds to community 3(a) of Grace (1966) and community 1 of Wood (1968). In Wellington Harbour, Paphies australe occurs in the upper margins of the sublittoral zone at Petone Beach, while Chione stutchburyi extends from below that level down to 6 to 8 metres; it is not found in such deep water in Bay of Islands. Substrates are probably too

silty at this depth for Paphies australe.

Grace's community 2(b) (Nucula - polychaete - Echinocardium - Paphirus - Atrina) may occur in some sheltered areas in both harbours (e.g. off stations B2, and B3 in Bay of Islands, and stations 4 and 24 in Wellington Harbour). In more sandy Zostera areas in Bay of Islands, Atrina pectinata zelandica and Nucula hartvigiana are supplemented by Pecten novaezelandiae (e.g. Rawhiti, off station B4).

Grace's communities 10b and 10c (Tawera, Glycymeris modesta and Tawera, Glycymeris laticostata, Astropecten) occur at the mouth of the Kerikeri Inlet in Bay of Islands (Fig.2.1, stations A18 and B12) although the distinction between the two communities is not clear. These two communities are equivalent to the Tawera spissa - Venericardia purpurata association described by McKnight (1969), and the Tawera formation (3,3a and 3b) of Powell (1937). Only in open areas with direct oceanic influence does Paphies subtriangulatum occur (station B5 and B8 in Bay of Islands) and this species is occasionally reported from beaches near the mouth of Wellington Harbour.

(b) Medium depth communities in New Zealand were described by Powell (1937) Estcourt (1967), McKnight (1968 and 1969), Morton & Miller (1968) etc. McKnight (1969) summarised the major communities of the continental shelf and their distribution. Some of his communities appear to occur in Bay of Islands and Wellington Harbour. It is emphasised that the identity of possible communities in Bay of Islands is based mainly on a few bivalves, often just dead valves. The Wellington Harbour invertebrate fauna in general was noted, but only live bivalves quantitatively recorded. The following observations for Bay of Islands are from the Petersen grab and sledge dredge surveys, while those for Wellington Harbour are from the anchor dredge surveys.

1. Amphiura rosea - Dosinia lambata.

This occurs north of Tasman Bay on sandy mud or muddy substrates and is recorded from Whangaroa Harbour. In Bay of Islands it may occur at

FIG. 6

FIG.2.6 BAY OF ISLANDS

The distribution of some bivalve molluscs (living) in the Kerikeri Inlet (see Fig.1.2). The salinity measurements were made with a Zeal hydrometer at low tide on the date given. The main areas of mudflats exposed at low tide are dotted.

Bivalve species:

1. <i>Chione stutchburyi</i>	9. <i>Nucula hartvigiana</i> .
2. <i>Xenostrobus securis</i> .	10. <i>Tawera spissa</i> .
3. <i>Mytilus edulis aoteanus</i>	11. <i>Venericardia purpurata</i> .
5. <i>Paphies australe</i> .	12. (<i>Glycymerula</i>) <i>modesta</i> .
6. <i>Arthritica bifurca</i> .	13. <i>Atrina pectinata zelandica</i> .
7. <i>Cyclomactra ovata</i> .	14. <i>Xenostrobus pulex</i> .
8. <i>Macomona liliana</i> .	15. <i>Perna canaliculus</i> .

Stations:

1. Kerikeri wharf.	4. Scudders Beach.
2. Upper Kerikeri Estuary 1.	5. Shelly Beach.
3. Upper Kerikeri Estuary 2.	6. Waireka West.

station A 19 and possibly at A1. It could be more widespread than the benthic sampling indicates.

In Wellington Harbour it may occur at stations 8, 33 and 48 and again may be more widespread than the results suggest. Alternatively it does not exist at all, and in these stations Dosinia lambata is co-dominant with Dosinia greyi. Amphiura rosea and Echinocardium daudatum occur commonly throughout most of the basin of Wellington Harbour.

2. Amphiura rosea - Dosinia greyi.

This occurs on muddy sand or sand from Fiordland north to Cape Turnagain, but also is recorded at Auckland Harbour. It appears to be the most widespread benthic community in Wellington Harbour, occurring at stations 2, 3, 10, 11, 12, 17, 19, 20, 29, 31, 34, 41, 42, 43, 46, 47, 49, 54 and possibly others. It was not observed in Bay of Islands.

3. Polychaete - Zenatia acinaces.

Occurring on fine substrates, it is often found in sheltered estuarine stations and has been recorded at Whangateau, Auckland and Akaroa Harbours. It may occur in Wellington Harbour (possibly station 50), but more commonly Zenatia acinaces seems to occur as co-dominant with Dosinia greyi in the Amphiura rosea - Dosinia greyi community. It was not observed in Bay of Islands.

4. Scalpomactra scalpellum - Maorimactra ordinaria.

This is widespread throughout New Zealand in mainly sandy substrates, and may occur in Bay of Islands at stations A15 and possibly A13. Scalpomactra scalpellum valves occur quite commonly at several stations, and the fragile valves, being subject to damage and rapid disintegration, may disguise the importance of this community in the bay.

This community may occur at station 28 in the Wellington Harbour entrance, but most of the harbour is probably too muddy and sheltered for it.

5. Tawera spissa - Venericardia purpurata.

Widespread throughout New Zealand in gravelly sand or sand, this community appears to be common in Bay of Islands (station A3, A11?, A14, A16, A17 and A18), and is synonymous with communities 10a, 10b and 10c

of Grace (1966) and 3, 3a and 3b of Powell (1937).

It may occur occasionally in Wellington Harbour, but in conjunction with other bivalve groups (stations 22, 23 and 28).

6. Nemocardium pulchellum - Pleuromeris zelandica.

Widespread throughout New Zealand on muddy sand and mud substrates, this community may also occur in Bay of Islands at stations A2, A4 and A10. Powell (1937) described this community from Auckland Harbour (3c and 3c 1). It was not observed in Wellington Harbour.

7. Nemocardium pulchellum - Dosinia lambata.

Although Nemocardium pulchellum was seldom taken alive in Wellington Harbour, dead valves were extensively dredged in the deeper basin area of the harbour. The fragility of the shell would cause rapid disintegration; hence possibly the Nemocardium pulchellum - Dosinia lambata community, or the co-dominant community with Dosinia lambata and Dosinia greyi, has recently been important but now no longer exists.

The considerable difficulty in allocating station samples to particular community-types demonstrates the limitations of the community concept, particularly in harbour situations such as Bay of Islands and Wellington Harbour, where a big range in substrates and depths may occur over very short distances. In more homogeneous continental shelf areas, definite and quite stable communities may, however, exist.

Wellington Harbour Agassiz trawls.

Whilst the Petersen grab and anchor dredge sample a section of substrate, the agassiz trawl tends to accumulate surface animals with little substrate penetration. The results (Table 2.7) are dominated by epifaunal bivalves (Perna canaliculus, Aulacomya maoriana, Chlamys zelandiae, Monia zelandica, etc.), substrate surface bivalves (Modiolarca impacta, Pecten novaezelandiae, Ostrea lutaria etc.) and species that protrude above the surface (Atrina pectinata zelandica). The remainder are species that occur

just below the substrate surface, and were collected during a gouge of the trawl.

Bivalves obtained by the anchor dredge and Agassiz trawl at the same station show considerable variation, emphasising the need for consistency of sampling method when comparing samples in benthic ecology. Agassiz trawls sampling large surface areas with little penetration are less indicative of species present than grabs or dredges, at least in substrates such as occur in Wellington Harbour, and the results are also less quantitative.

Wellington Harbour - other data.

Sampling in benthic ecology is complicated by the wide variation of fauna that may occur over short distances. Only the most sensitive survey with stations very closely sited can adequately describe faunal variations, and this may require much time and expense.

The 55 stations sampled in Wellington Harbour are indicative of the fauna present, but the data from other random collections is useful in demonstrating faunal variations over short distances. Table 2.8 tabulates the results. The sampling site is fitted to the nearest station from Fig.2.2. The sledge dredge sampled a far larger surface area than the anchor dredge, taking surface and subsurface bivalves, although species that occurred commonly in the stations listed in Fig.2.8 generally also occurred in the nearby stations in Fig.2.2.

2. Epifauna.

(a) Epifaunistic communities of rocks and stones.

Dell (1954) reviewed the few studies made on deep-water rock faunas in New Zealand. No observations could be made for this report.

The littoral and upper sublittoral epifaunal communities of New Zealand are discussed by Oliver (1923) and Morton & Miller (1968). Intertidal transects for Uruti Bay (near Russell) in Bay of Islands and

parts of Wellington Harbour are described by Morton & Miller (1968).

The distribution of the main shore types in Bay of Islands was given in Fig.1.4. Flaws (1968) gave the distribution of shore types for Wellington Harbour.

(1) Rock oyster community (Crassostrea glomerata)

This is the most obvious rock community in Bay of Islands, and is described by Oliver (1923), Grace (1966) (Community 8 - Elminius - Crassostrea) and Morton & Miller (1968). It occurs intertidally in all estuarine areas, and sporadically in higher salinity areas (station B6, B7 etc.) The occurrence of other oyster species in Bay of Islands is described by Dinamani (1971). The oysters provide shelter for the small Leptonaceans Lasaea rubra, occurring commonly throughout the bay, and Lasaea maoria. At station B1, Lasaea rubra occurs in large numbers with the barnacle Elminius plicatus.

This community does not occur in Wellington Harbour, although Bell and Climo (1971) do record the presence of Crassostrea glomerata.

(2) Mussel community.

The Mytilius edulis community of Sparck (1935), represented in Bay of Islands and Wellington Harbour by Mytilius edulis aoteanus, is described by Oliver (1923). Morton & Miller (1968) recorded Bay of Islands as an isolated northern occurrence of the species. Mytilius edulis^{aoteanus} is replaced by Xenostrobus pulex (community described by Oliver, 1923) above and Perna canaliculus below in the inter-tidal species sequence. The settlement of Mytilius edulis aoteanus in Bay of Islands, like Chione stutchburyi, has been sporadic over the last few years. Mr.D.E.Flaws (pers. com.) observed few individuals in Wairoa Bay (station B1) in summer 1967, but large numbers of this species have since become established.

Mytilius edulis aoteanus occurs in estuaries and bays, whilst Perna canaliculus requires more open water.

Xenostrobus securis replaces Xenostrobus pulex in brackish water, (described by Oliver, 1923). Aulacomya maoriana occurs commonly in Wellington Harbour with Perna canaliculus, but this species is uncommon in Bay of Islands.

(3) Crevice fauna and boring bivalves.

Morton & Miller (1968) discussed these communities. Lasaea maoria occurs commonly in Bay of Islands and Wellington Harbour, and Kellia cycladiformis less frequently. The soft rock borer Barnea similis occurs commonly at several stations in Bay of Islands (B1, B3, B8 and B9) and uncommonly in Wellington Harbour. The Leptonacean Arthritica crassiformis was observed commensal with Barnea similis at stations B1 and B9 in Bay of Islands. This commensal relationship was described by Ponder (1965). Other bivalves occurring commonly as secondary invaders of borings include Irus reflexus and Protothaca crassicosta.

(4) Other rock epifauna.

These include Barbatia novae^azelandiae, common near station B1 in Bay of Islands, and Chlamys (Mimachlamys) zelandiae, Borniola reniformis and Modiolarca impacta common throughout both harbours.

(5) Epifaunistic communities of vegetation.

No observations were made on these communities, but Gregariella barbata and Cardita brookesi occur in seaweed holdfasts (Mrs. L. Seager, pers com.).

SPECIES ABUNDANCE IN BAY OF ISLANDS AND WELLINGTON HARBOUR.

Tables 2.9 and 2.10 list the most abundant bivalve species occurring in the harbours. The list for Bay of Islands was compiled with the assistance of Mrs. L. Seager, Opua; that for Wellington Harbour was compiled mainly from anchor dredge and agassiz trawl samples.

The tables have been prepared only as an approximate guide to the most abundant species of the families in each harbour. No specific criteria have been used, because of the wide range of sampling techniques used.

The tables are based mainly on the general impression of abundance of the species gained from all the observations combined. The abundance of midlittoral species can quite readily be estimated and compared, but their abundance relative to that of sublittoral species, whose distribution and abundance are often difficult to determine, may be of little meaning. Also, species which are common and widespread will have greater overall abundance in the harbour than those which occur abundantly only in confined areas.

COMPUTER ANALYSIS OF WELLINGTON ANCHOR DREDGE SURVEYS.

There have been several strategies developed to analyse species occurrence at station matrices obtained in benthic surveys. Stephenson, Williams and Lance (1970) and Stephenson (1972 - in press) discussed the use of various coefficients of similarity and dissimilarity of station components and species distributions. Stephenson, Williams and Cook (1972) used the Canberra metric coefficient as a dissimilarity measure in the analysis of the data of Petersen (1914). Using the Canberra metric coefficient, Similarity is measured by the following equation:

$$\frac{1}{J} \sum_j \frac{x_{1j} - x_{2j}}{x_{1j} + x_{2j}}$$

x_{1j} = number of the j^{th} species at site (= station) 1.

Its advantage over similar coefficients (e.g. Bray - Curtis) is that it is a sum of a series of fractions, and a very abundant species can contribute to only one of the fractions.

The Wellington Harbour anchor dredge data seemed suited to analysis with this coefficient, and Professor W. Stephenson kindly carried out the computerisation. The data was treated in the following manner:

1. Species with single occurrences were eliminated.
2. The Canberra metric coefficient of association was applied, with zero in zero/non zero matches adjusted to 0.2. This

TABLE 2.9 Species Abundance in Bay of Islands

Classification based on Powell (1961), but with some modification

Family	Species		Distribution
	abundant	common	frequent
Nuculidae		Nucula hartvigiana	estuaries
Nuculanidae			Nucula nitidula basin
			Nuculana bellula basin
			Poroleda lanceolata basin
			Neilo australis basin
Arcidae			Barbatia novaezealandiae basin
Glycymeridae		(Glycymerula) modesta	basin
Mytilidae		Mytilus edulis aoteanus	estuaries
		Perna canaliculus	basin
		Xenostrobus pulex	basin
			Modiolus areolatus basin
			Modiolarca impacta basin
			Atrina zelandica throughout
Pectinidae			Pecten novaezealandiae basin
		Chlamys zelandiae	basin
Anomiidae		Anomia walteri	basin
Ostreidae			Ostrea sp. throughout
	Crassostrea glomerata		throughout
Carditidae			Venericardia purpurata basin
Diplodontidae			Diplodonta zelandica basin
Lucinidae			Divaricella huttoniana basin
Lasaeidae			Kellia cycladiformis basin
	Lasaea rubra		throughout
			Lasaea maoria throughout
			Borniola reniformis basin
Erycinidae		Arthritica bifurca	throughout
Cardiidae			Nemocardium pulchellum basin
Veneridae			Dosinia lambata basin
			Dosina zelandica basin
	Tawera spissa		basin
	Chione stutchburyi		estuaries
			Venerupis largillierti basin
Tellinidae		Macomona liliana	estuaries
Semelidae			Leptomya retiaria basin
Sanguinolariidae			Gari stangeri basin
Mactridae			Gari lineolata basin
			Scalpomactra scalpellum basin
Mesodesmatidae	Paphies australe		estuaries
Corbulidae		Caryocorbula zelandica	basin
Pholadidae			Barnea similis estuaries
Teredinidae			Bankia australis

TABLE 2.10 Species Abundance in Wellington Harbour

Classification based on Powell (1961),
but with some modification

Family	Species		
	abundant	common	frequent
Nuculidae		Nucula hartvigiana Nucula nitidula	
Mytilidae	Mytilus edulis aoteanus Perna canaliculus	Aulacomya maoriana Modiolarca impacta	
Pinnidae			Atrina zelandica
Pectinidae		Chlamys zelandiae	
Ostreidae		Ostrea lutaria	
Carditidae			Venericardia purpurata
Diplodontidae			Diplodonta striatula
Lasaeidae		Lasaea rubra	Lasaea maoria
Erycinidae	Arthritica bifurca		
Veneridae		Dosinia lambata Dosinia greyi	Dosinia zelandica Tawera spissa
	Chione stutchburyi		Venerupis largillierti
Tellinidae			Angulus edgari Macomona liliana
Semelidae		Leptomya retiaria	
Sanguinolariidae			Gari lineolata Gari stangeri Zenatia acinaces
Mactridae			
Mesodesmatidae		Paphies australe	
Corbulidae	Caryocorbula zelandica		
Myochamidae			Myadora striata
Thraciidae			Thracia vitrea

eliminated the problem of $\frac{x_1 - x_2}{x_1 + x_2}$ being equal to 1 when x_2 is 0.

3. Of the various hierarchical strategies available (listed by Lance and Williams, 1967), flexible sorting has been used with the best results in marine benthic surveys, and was used here.
4. Normal and inverse analyses were made. (Normal analysis is the classification of stations, grouping stations that are similar, using the occurrence of species at each station as the attributes. Inverse analysis is classifying species using the station data as the attributes).
5. The number of groups generated (usually approximately the square root of the number of entities) were 7 station groups and six species groups.

Table 2.11 gives the stations and species.

The resulting dendrogram for the normal analysis of stations is given in Fig.2.7, and for the inverse analysis of species in Fig.2.8. The distribution of the station groups in Wellington Harbour is plotted in Fig.2.9. Station groups 47 and 61, separated on the basis of numbers of individuals, have been combined.

Normal classification of stations (Fig.2.7)

Station group 1 (47 and 61)

Dosinia greyi is the sole species, and is distributed over much of the western silty pelite basin of the harbour. It is the most successful species in this very fine substrate.

Station Group 2 (79)

The eastern silty pelite basin is occupied by Dosinia greyi with other mud species ((^uEnnucula) strangei, Dosinia lambata etc.), as well as muddy sand species towards the edges. There is a large increase in species diversity, possibly due to the freshwater influence of the Hutt River and

the slightly coarser substrates available in the area.

Station Group 3 (78)

This station group occurs in more shallow areas (although it is not determined by depth) on sandy pelite through to sand. There is a big species diversity in a wide range of sediments. Sand species, particularly Gari lineolata, occur commonly, and Dosinia greyi is not strongly represented. This station group is very similar to station group 2 in both species diversity and the species present.

Station Group 4(70)

Although this station group occurs in silty pelite on the harbour edges and south of Somes Island, it is not determined by depth. Species diversity is low; Dosinia greyi is common, and is associated with three largely mud species (Zenatia acin^{aces}, Dosinia lambata and Thracia vitrea).

Station Group 5 (77)

This station group occurs in sand near the harbour mouth, and has relatively low species diversity with sand and some sandy mud species, and no Dosinia greyi are present. I have included station 26 in station group 2 where it gives a better fit.

Station Group 6(23)

In coarse sand at the harbour mouth, a few sand species (Scalpomactra scalpellum and (Glycymerula) modesta) and again no Dosinia greyi.

Station Group 7 (80)

In sandy and very sandy pelite areas at the harbour edges (although not determined by depth), this station group includes mud to sand species dominated by Venerupis largillierti, but with no Dosinia greyi.

Station Group 8 (75).

This station group occurs in sandy or very sandy pelite areas in shallow water, with water depth the main determining factor. The dominant species (Chione stutchburyi, Macomona liliana and Paphies australe) occur

at low tide level or just below on sand or sandy mud beaches, while the other species have wide depth ranges. Dosinia greyi does not occur.

Station Group 9 (17)

Occurring in sandy or very sandy pelite areas, this station group includes sand to mud species and no Dosinia greyi. This station group is similar to station group 3, although the species diversity is lower.

The plotting of the station groups in Fig.2.9 indicates good correlations with substrate types, with greatest rate of change in station groups occurring in regions of greatest sediment variability towards the harbour mouth.

Inverse classification of species (Fig.2.8)

The chaining in the dendrogram indicates indistinct species groups in the harbour. The most distinct separation is between species groups 1 - 5 (mud to sand species) and species group 6 (exclusively coarse sediment and sand species).

Species groups 1 and 2 are those occurring mainly in mud or muddy sand. Species group 3 are species occurring mainly in shallow water, but exclude Chione stutchburyi. Group 4 are mainly sandy mud or sand species. Group 5 are the numerically most abundant species in the harbour. Group 6 are almost exclusively sand or coarse sediment dwellers.

In summary, the classification of the stations shows considerable correlation with the harbour substrate types, while the classification of the species suggests poor classical community structure. Thus the most applicable model for Wellington Harbour seems to be the distribution of individual species over suitable substrates within suitable hydrological environments; the coincidence of species distribution patterns give

TABLE 2.11.

WELLINGTON HARBOUR

Two-way table of station-species derived from Anchor
Dredge survey, Table 2.6

Species with single occurrences were eliminated.

Stations which then had zero bivalve occurrences were eliminated,
and station numbers were adjusted from those given in

Table 2.6 and Fig. 2.2 to give a continuous series 1 - 45.

The station localities, for identification on Fig.2.2, are
given in brackets.

TABLE 11

[illegible]

FIG. 2.7 Dendrogram of normal classification of
stations (anchor dredge surveys),
Wellington Harbour.

FIG 2.8 Dendrogram of inverse classification of species
(anchor dredge surveys),
Wellington Harbour.

FIG. 7

FIG. 8

FIG. 2.9

WELLINGTON HARBOUR

Distribution of station groups (from anchor dredge surveys).

Stations yielding no live bivalves are shown by unfilled circles. The station marked with (?) and an unfilled circle yielded no live bivalves, and was not assigned to any station group. The contours are of grain size distribution, from Van der Linden (1967) (see Fig. 2.5)

station similarities, hence station groupings. However, the tendency for the same species to re-occur together is weak, suggesting that the distribution patterns of individual species rarely coincide with any exactness.

The comparison of these conclusions to those obtained earlier by visual assessment of the samples suggests that it was little more than a coincidence that any of the benthic stations fairly fitted previously-described communities. The value of the classical community concept to the Wellington Harbour benthic data has been only that it can describe in the most general terms the sorts of bivalves occurring.

CONCLUSIONS

The bivalve fauna of Bay of Islands and Wellington Harbour has been discussed, and bivalve species groups occurring in both harbours have been visually compared to previously-described communities for New Zealand. The community concept has been found to be useful for describing in general terms some shallow water and epifaunal groups of bivalve species occurring in the harbours. However, because of the difficulty in allocating bivalve species groups to the previously-described community types, the concept appears to be largely inadequate in other shallow water areas, and in medium depth areas, particularly in Wellington Harbour. The concept is therefore least adequate in areas where substrates change profoundly over short distances, and is probably most valuable in areas of small environmental variability.

In anchor dredge sampling of 55 benthic stations in Wellington Harbour, the distribution of many bivalve species closely followed sediment types. Station groups, using the species present at each

station as the criteria, also showed close correlations to the sediment types. Sediment type therefore appears to be the most important single factor in the occurrence of a species at a station, assuming the hydrological environment at the station is suitable. The presence or absence of other species is usually of no consequence.

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SECTION 3.

DESCRIPTION AND SEASONAL OCCURRENCE

OF

SOME COMMON NEW ZEALAND BIVALVE LARVAE.

WITH NOTES ON

THE SPAWNING CYCLE OF SOME ADULTS.

SUMMARY

Observations were made on the occurrence of common late stage bivalve larvae in the plankton at Bay of Islands and Wellington Harbour during 1970 - 71. Three stations in Bay of Islands and four stations in Wellington Harbour were sampled approximately monthly.

The bivalve larvae in shorter series of plankton samples from Raumati Beach, Dargaville Beach, Mahurangi, Ohiwa Harbour, Raglan Harbour and Kaipara Harbour during 1971 - 72 were also analysed.

Twenty-nine species of bivalve larvae from these plankton samples are described. Twenty-three species of late stage bivalve larvae are provisionally identified, the identifications being based on the larval hinge structure, the distribution and abundance of the larvae in relation to adult stocks, and in some cases by correlation with the adult gonad or condition index cycle.

The broad seasonal pattern of occurrence of twentyfive species of late stage bivalve larvae in the plankton at Bay of Islands, Wellington Harbour and Raumati Beach is presented.

INTRODUCTION

This section deals with the bivalve larvae, in particular the late stage forms, encountered in plankton samples taken mainly at Bay of Islands and Wellington Harbour during 1970 - 71.

TYPES OF BIVALVE LARVAE

Developmental types of bivalve larvae were described by Miyazaki (1962) Ockelmann (1965), Sellmer (1967) and Chanley (1969). Miyazaki described four marine types, while Ockelmann described three, with brood protection (incubation) occurring in all. Chanley discussed these groupings, and classified all developmental types into

1. Protobranch - most primitive type with lecithotrophic larvae developing in a ciliated test. e.g. Yoldia limatula (Drew, 1901).
2. Pandoracean - lecithotrophic larva with short planktrophic pelagic period, occurring in superfamily Pandoracea.
3. Veliger - short lecithotrophic stage followed by planktrophic stage. The original veliger shell, secreted by the shell gland, is probably homologous to the Pandoracean larva. This is the most advanced bivalve larval type.
- 4 and 5. Glochidium and Lasidium larvae in freshwater species, involving a parasitic stage.

This classification involves an evolutionary trend towards increased dispersal of larvae, for example, by the lengthening of the larval period (veliger) and the development of a parasitic stages (glochidium and lasidium), and a second evolutionary trend towards protection of larvae through incubation. Developmental sub-classification due to the occurrence of incubation is: (after Chanley, 1969)

1. Pelagic development - fertilization external, free-living throughout larval development, planktotrophic during shelled stages.
2. Hypolarviparous development - fertilization internal. incubation from a few hours to two days, released as young planktotrophic larvae,
3. Larviparous development. Incubation through half of larval period, released as half-grown larvae,

planktotrophic after release.

4. Hyperlarviparous development - incubated through almost entire larval period, released as larvae just prior to or during metamorphosis.
5. Direct development - incubated through entire larval period, and released as juveniles.

This study deals in particular with veliger larvae, and unless stated otherwise, "bivalve larvae" refers solely to veliger larvae.

Typical veliger development has been described by many workers e.g. (Miyazaki, 1935 , Mair 1956, Creek 1960 etc.) In summary, fertilized eggs undergo normal protostomial embryological development to a trochophore stage to a veliger. Ockelmann (1965) found in general a straight line relationship between the egg size and the size of the larval shell, and also for the size of the larval shell and the size of the adult shell, provided the species have the same type of development.

Pelagic development is the most common veliger developmental subtype in New Zealand, although probably all five subtypes do occur. In most species the larval shell appears about two days after fertilization and is composed of a thin layer of conchiolin-like material secreted by the shell gland, and is at first uncalcified (Ansell, 1962). This first formed region is distinguished in larvae of all ages, and is known as the prodissoconch 1 or straight-hinged or D-shaped veliger shell (Werner, 1939 , Rees, 1950, Carriker, 1961). The rest of the larval shell, prodissoconch 2, is secreted in the normal way by the outer edge of the mantle, is thicker than prodissoconch 1, and often bears concentric markings. The late stage veliger larva, consisting of prodissoconchs 1 and 2, is the veliconcha stage (Werner, 1939, Rees, 1950) or unboned stage (Carriker, 1961). Many species are able to postpone metamorphosis while seeking a suitable substrate for the young bottom dwelling postlarva or dissoconch

(Werner, 1939, Rees, 1950). Carriker (1961) called this the pediveliger stage, in which the veliger develops a strong ciliated muscular foot and for an indefinite period alternates between a planktonic and a benthic habit. This stage has been widely observed in bivalve veligers (Le Bour, 1938 b, Jorgensen, 1946 etc.).

This study deals mainly with late stage larvae (veliconcha) and early pediveligers, the most distinguishable stages in bivalve larval development. Pediveligers are defined more by their soft parts than by their shells, and resemble late stage larvae in appearance.

D-shaped larvae of different species are usually similar in appearance and very difficult to distinguish (Creek, 1960). Even late stage larvae and pediveligers of different species often closely resemble each other, and Stafford (1912) wrote of them "those of the same species at distant intervals may appear as unlike one another as different species. It is difficult to find a point of departure in distinguishing them." MacBride (1914) in fact postulated that veliger larvae were so similar in appearance they could not be distinguished at all, and that differentiation of species occurred during postlarval life.

PREVIOUS WORK.

The larvae of about 3% of the 15,000 extant bivalve species have been described (Chanley, 1969). Quayle (1952), Loosanoff, Davis and Chanley, (1966), and Chanley and Andrews (1971) present historical reviews of the literature pertaining to the description and identification of bivalve larvae. The main works to which I refer in this study include those of Le Bour (1938b), who described fifteen larval species occurring at Plymouth, and related their occurrence in the plankton to the adult breeding, and to postlarval development, Sullivan (1948) who described twentytwo species of larvae from Malpeque Bay, PEI, mainly by relating late stage larvae to early dissoconch shells, Rees (1950) who described seventyeight species of larvae from the North Sea and produced a

classification of larval hinge structures, Jorgensen (1946) who described about fifty species of Danish larvae, Miyazaki (1962) who studied two hundred species and classified them into twenty principle types of larva, Loosanoff and Davis (1963) who included observations on nineteen species reared in the laboratory, Loosanoff, Davis and Chanley (1966) who gave details of the larval development of twenty species (including the nineteen species of Loosanoff and Davis, 1963), and Chanley and Andrews (1971) who described by larval rearing an additional three species.

Few New Zealand bivalve larvae have been described or identified. Rapson (1952) described the larval development of Amphidesma ventricosum and Hollis (1963) described the larval development of Ostrea lutaria, both authors using line drawings. Dawson (1954) gave a photomicrograph of the late stage larva of Amphidesma subtriangulatum. Rainer (1966) gave shaded diagrams of the late stage ^{larva of} Crassostrea glomerata. Booth (1969) described the larval shell shape of thirteen late stage bivalve larval species from Bay of Islands, with photomicrographs and line drawings. Dinamoni (1971) gave a photomicrograph of D-shaped larvae of Ostrea sp. from Bay of Islands just prior to release, and Dinamoni (1973) describes the larval development of Crassostrea glomerata with photomicrographs.

The seasonal occurrence of bivalve larvae in New Zealand have received still less attention. Rapson (1952), Dawson (1954) and Rainer (1966) gave the times of occurrence of their larvae in the plankton during relatively short sampling periods. Jillett (1971) ^{the} described/occurrence of total bivalve larvae at two stations in the Hauraki Gulf during 1963 - 5.

TERMINOLOGY.

I use the terminology employed by Chanley and Andrews (1971) for larval shell descriptions (Fig .3.1) which differs from Rees (1950)

in that "breadth" is replaced by "height", and "convexity" by "depth."

The larval hinge characters are described by Rees (1950). In brief, the fully developed hinge system often consists of two parts - the provinculum or thickened straight part of the hinge, bearing provincular teeth or tooth-like projections, and the lateral hinge system extending beyond the provinculum. The features are given diagrammatically in Fig.3.2 (from Rees, 1950).

Other larval terminology relating to umbo shape (round, broadly round, angular, knobby, skewed), shoulders (curved, straight, length, steepness of slope, anterior compared to posterior), ends (length, blunt, pointed, anterior compared to posterior) and ventral margin (round, flat, semicircular), etc. is according to Chanley and Andrews (1971).

EVALUATION OF METHODS OF LARVAL DESCRIPTION AND IDENTIFICATION.

The most useful larval descriptions are those made on the shell characters, since most commonly observations are made on preserved samples. The most distinctive features are the dimensions, shape, colour, texture and sculpturing, thickness, and hinge characters. Dimensions include length, height, depth, and their ratios, angle at hinge apex, and ratio of hinge length to shell length or height. Useful soft part characters include the presence of an eyespot, byssal notch, apical flagellum etc.

Most larval descriptions have included dimensions, which are important since different species may closely resemble each other in shape at different or similar stages of development.

Larval shape, based on the umbos, shoulders and ends, has been mostly widely used in larval descriptions. Some workers have formulated specific larval shape groupings into which all larvae studied could be fitted. For example, Sullivan (1948) grouped the larvae of Malpeque Bay into six principle shape-groups. Larval shapes described by photomicrographs are preferable to line drawings because of their objectivity (Sullivan, 1948, Rees, 1950, Quayle, 1952, Loosanoff, Davis and Chanley,

1966 etc.).

Larval colour is either due to pigmentation in the shell itself, or to the colour of the soft parts. Shell pigmentation will last indefinitely if the larvae are properly preserved, but the colour of the soft-parts is generally **lost** on preservation. Many workers have considered colour to be ^auseful descriptive feature (Jorgensen, 1946, Knight Jones, 1954, Ota, 1961, Carriker, 1961, Chanley & Andrews, 1971, etc.), but Loosanoff (1961) maintained that it was not a dependable criterion, since he found laboratory larvae assumed the colour of the food eaten.

Rees (1950) used shell texture sculpturing when sufficiently distinctive for larval descriptions. Ansell (1961) was able to distinguish prodissoconchs 1 and 2 in the larvae of Venus striatula by the prodissoconch 1 shell bearing small punctate markings, while the prodissoconch 2 shell had concentric lines of varying clarity.

Hinge characters have been used to describe larvae by several workers, e.g. Werner (1939), Rees (1950), Chanley and Andrews (1971) etc.

Some soft-parts may be useful in live or well preserved larvae. D'Asaro (1967) reviewed soft part characters that can be seen in living material or in serial sections, and that can be used in conjunction with other methods of description. Soft part characters include larval retractor muscles, larval eyes, apical flagella, the position of the coiled intestine, the structure of the gills and of the byssal notch (D'Asaro, 1967) and the size of the **velum** (Carriker, 1961), Knight Jones (1954) and Carriker (1961) suggested that swimming patterns of larvae are also a useful descriptive feature.

The two main types of methods for identifying bivalve larvae are:

1. Direct methods - the rearing of larvae from known adults.
2. Indirect methods -

Rees (1950) stated that "the surest method of determining the species of a larva is by culturing". Loosanoff, Davis and Chanley (1966) and Chanley and Andrews (1971) review the development of larval culture (laboratory rearing) techniques.

Indirect methods are limited by their lack of positive species identification, but are often the only methods available. The main ones include:

1. Removal of larvae from the plankton and the rearing of them to an identifiable stage of development.
2. Culturing larvae within the plankton sample (used by Stafford, 1912 and Miyazaki, 1962 etc.)

Methods 1 and 2 require the identification of the postlarvae or juvenile forms, many of which are almost identical (Carriker, 1961 and Quayle 1962).

3. Relating abundance of larvae in the plankton to the reproductive potential of the adults (Miyazaki, 1962).
4. Comparing prodissoconch 2 shell shape and dimensions to dissoconch shell shape and dimensions seen on the postlarvae. (Many workers, e.g. Rees, 1950, Jorgensen, 1946, Miyazaki, 1962 etc.)

Surface sculpturing, strength and colour of the shell and some soft-part characters (e.g. eyespot) may help. The main problems are that the prodissoconch 2 shell shape may become partially disguised, and that larvae of the same species may metamorphose at different sizes (e.g. Anomia simplex, Loosanoff, 1961).

5. Larval hinge characters. Rees (1950), in the most comprehensive review of larval shell hinge characters, classified North Sea bivalve larvae into eighteen basic hinge types, each type being characteristic of at least one family. More recent work has shown that most

of the family hinge groupings have world-wide application. Since hinge characters develop during larval development, and may be reduced or lost just after metamorphosis (Rees, 1950 Yoshida, 1953, and 1956), only larvae at similar stages of development can be compared.

6. Relating the occurrence of larval species to the adult species present in the area. Rees (1950) employed this method to specifically identify some broadly classified larval species.
7. In incubating species, the removal of larvae from the brood chamber.

Adult spawning cycles.

The technique of relating the spawning cycle of the adult to the occurrence of a particular larva in the plankton as a method of identifying bivalve larvae was mentioned above.

Giese (1959) summarised the methods for determining the annual reproductive cycle of marine invertebrates. The methods used most widely for bivalves include:

- (a) Observations on spawning in the field or the determination of the spawning potentiality value (e.g. Ansell and Loosmore, 1963, and Stickney, 1963 overseas. Graham, 1941, for some Gastropods, and Hollis, 1963 in New Zealand).
- (b) Occurrence of larvae in the field (e.g. Stafford, 1912, Le Bour, 1938b, Sullivan, 1948 overseas), or occurrence of larvae in conjunction with a microscopical examination of the gonads (e.g. Calabrese, 1969 and Berg, 1969 overseas).

Rapson, 1952 in New Zealand), or the settlement of larvae (e.g.

Pfitzenmeyer, 1962 overseas. Rapson, 1952, Hollis, 1963 and Greenway, 1969b in New Zealand).

(c) Microscopical examination of the gametes.

Gonadal smears (e.g. Battle, 1932, Reddiah, 1962 and Moore & Reish, 1969 overseas), but the method is of doubtful use (Cole, 1942).

Histological sectioning (e.g. Loosanoff, 1953, Ropes, 1968 overseas. Hollis 1963, Dinamani 1973 in New Zealand).

(d) In incubatory species, the occurrence of the larvae in the brood chamber (e.g. Hopkins, 1936, Millar, 1964, Oldfield, 1964, overseas. Hollis, 1963 and Tunbridge, 1962 in New Zealand).

(e) Gonad index. Used mainly on Gastropods (Booolootian, Farmanfarmaian and Giese, 1962 etc.), but also with Pectinids (Sastrey, 1966, 1968 and 1970 overseas. Tunbridge, 1968 in New Zealand) and Crassostrea virginica by Loosanoff, (1965) overseas.

Other methods not recorded by Giese (1959) include

(f) Condition index. The general appearance or "condition" of the animal or its gonad (e.g. Chipperfield, 1953, Mason, 1957 overseas. Choat, 1960 and Tunbridge, 1968 in New Zealand). "Condition Index" was developed as a measure of this state, and relates the weight or volume of the flesh to the total shell plus flesh weight or volume. There is generally an annual cycle of the condition index, and although the reasons for the cycle are not fully understood, contributing factors are the build-up of glycogen and reserves and gametes prior to spawning, the loss of body weight after spawning (Haven, 1960). Medcof and Needler (1941) found a correlation between the condition and spawning cycles of Ostrea virginica, and Ansell and Loosmore (1963) found a direct correlation between the mean condition & the spawning potentially of a population of Venus mercenaria adults.

There have been few accounts of the spawning season of New Zealand marine bivalve molluscs. Table 3.1 lists some examples. Most have been

derived from observations on the settlement of spat, and these are of limited value since the settlement surfaces may not always be available to the planktonic larvae.

The table suggests that the same species may have different spawning periods at different localities, and that some species spawn throughout the year at some localities.

TABLE 3.1 The Spawning seasons of some New Zealand marine
Invertebrates (Bivalves)

Species	Location	Spawning Period	Method of Determination	Source
<u>Mytilus planatulus</u>	Wellington Harbour	throughout year	settlement	Ralph and Hurley (1952)
<u>Mytilus edulis aoteanus</u>	Lyttleton Harbour	late September - May	histological.	MacDonald (1963)
<u>Mytilus edulis aoteanus</u>	Wellington Harbour	May & June (observations made March - June only)	settlement	Colgate (1971)
<u>Perna canaliculus</u>	To Kouma, Coromandel	Mainly in spring, also in summer & a little in autumn & winter.	settlement	Greenway (1969b)
<u>Perna canaliculus</u>	Lyttleton Harbour.	January - early April	histological & settlement	MacDonald (1963)
<u>Perna canaliculus</u>	Kenepuru Sound	Mainly January - March (observations made January - June only).	settlement	Brunette (1970)
<u>Pecten novaezelandiae</u>	Tasman Bay	August - March, or mainly March & some in August - September.	gonad	Choat (1960)
<u>Pecten novaezelandiae</u>	Tasman Bay	March - June	gonad index	Tunbridge (1968)
<u>Anomia walteri</u>	Port of Auckland	Mainly in April, May. Also in November & December, and a little January - March.	settlement	Skerman (1959)

marine invertebrates. (Bivalves)

Species	Location	Spawning Period	Method of Determination	Source
<u>Ostrea sinuata</u>	Wellington Harbour	August - March, but possibly whole year with maximum in summer.	larval occurrence	Hollis (1963)
<u>Ostrea lutaria</u>	Foveaux Strait.	mid-December - mid-February	settlement	Cranfield (1968)
<u>Ostrea sp.</u>	Northland	December - May	larval occurrence	Dinamani (1971)
<u>Crassostrea glomerata</u>	Kaipara Harbour	mid-December - early April	settlement	Rainer (1966)
<u>Crassostrea glomerata</u>	Mahu rangi	January - March	settlement	Greenway (1969d)
<u>Amphidesma Ventricosum</u>	Dargaville Beach.	October - June	settlement larval occurrence.	Rapson (1952)
<u>Bankia australis</u>	Wellington Harbour.	throughout year.	settlement	Ralph & Hurley (1952)
<u>Bankia australis</u>	Otago Harbour.	throughout year, except July & early August.	settlement	Hurley (1959)
<u>Bankia sp.</u>	Wellington Harbour.	May (observations made March-June only).	settlement	Colgate (1971)

LABORATORY REARING EXPERIMENTS.

Direct methods (the rearing of larvae from known adults) have already been described as the surest method for identifying bivalve larvae. Equipment was set up at the Island Bay Marine Laboratory in 1971, based on that described by Loosanoff and Davis (1963), for the laboratory rearing of bivalve larvae, and included an adjustable heat salt water supply, algae drip food supply, constant temperature larval rearing trays, and ultra-violet sterilization equipment. Attempts to stimulate spawning in most of the common bivalve species from Wellington Harbour met with

virtually no success, even when gonadal smears showed the adults to be sexually mature.

Attempts were also made to condition adults of several species for out of season spawning by using a constant supply of warm water (Loosanoff and Davis, 1950), but again there was little success.

More extensive experiments are required on New Zealand species of bivalve molluscs to determine spawning stimulants and requirements.

SAMPLING AREAS

PLANKTON

Bivalve larvae were sampled approximately monthly at Bay of Islands and Wellington Harbour from May 1970 to January 1972, but some collections were also made at other areas in New Zealand (Fig.3.3A) during this period.

Plankton collections in Bay of Islands were made at the three plankton stations given in Fig.3.3C (for exact positions, see Table 1.1), and in Wellington Harbour at the four plankton stations given in Fig.3.3 B (also see Table 1.1). Other stations occupied at both harbours will be described later.

Station positions in other sampling areas in New Zealand (Fig.3.3 A) will be given with the results.

ADULTS

The adults of several bivalve species were collected in Bay of Islands and Wellington Harbour for the determination of their spawning or condition cycles. The frequency and number of collections of the adults are given later with the larval descriptions and occurrences.

<u>Mytilus edulis aoteanus</u>	Powell	Bay of Islands - Wairoa Bay Wellington Harbour - Karaka Bay
<u>Perna canaliculus</u>	(Gmelin)	Bay of Islands - Wairoa Bay Wellington Harbour - Karaka Bay
<u>Modiolarca impacta</u>	(Hermann)	Wellington Harbour - Mahanga Bay

<u>Lasa ea rubra hinemoa</u>	Finlay	Bay of Islands - Wairoa Bay
<u>Arthritica bifurca</u>	(Webster)	Wellington Harbour - Petone Beach.
<u>Arthritica crassiformis</u>	Powell	Bay of Islands - Te Puna Inlet.
<u>Tawera spissa</u>	(Deshayes)	Bay of Islands - Waireka.
<u>Chione stutchburyi</u>	(Gray)	Bay of Islands - Wairoa Bay Wellington Harbour - Petone Beach.
<u>Paphies australe</u>	(Gmelin)	Bay of Islands - Shelly Beach.

METHODS

PLANKTON SAMPLING PROGRAMME

At the outset of the project I was uncertain of the length of larval life and the seasonal occurrence of New Zealand bivalve species in the plankton, since this information for New Zealand species is scarce. Overseas studies give pelagic periods often exceeding two weeks, with most species spawning for several months (Le Bour, 1938b, Chanley and Andrews, 1971 etc.) It was decided that, although more frequent sampling was desirable, monthly sampling was the most frequent I could manage if both Bay of Islands and Wellington Harbour were to be sampled, and that this sampling programme would give a broad seasonal pattern of the larval occurrence of common bivalve species.

The difficulty in arranging boats, and the problem of adverse weather, made it impossible to sample every month at the same time of the month. The outer Bay of Islands plankton station (Waewaetoria) could not be sampled at all on some months because of poor weather conditions.

Similarly, plankton samples could not always be collected at the same time of the day or stage of the tide. The use of a net collecting plankton from the surface to the bottom largely eliminates the problem of bivalve larvae migrating vertically within the water column under varying light intensities. But the effect of alternating tides (ebb and flood) in estuaries is more profound, and this is discussed fully in Section 4. Suffice to say here that the Confluence plankton station in Bay of Islands

FIG.3.1 Diagrammatic illustration of the terminology used to describe dimensions of bivalve larvae, adapted from Chanley and Andrews (1971). For fuller definitions of terms, refer to Chanley and Andrews.

FIG.3.2 Larval hinge features.
(simplified, from Rees, 1950).
A diagrammatic illustration of the inside (above) and dorsal (below) views.
For fuller definition of terms, refer to Rees (1950).

FIG.3.3

A. Plankton sampling areas.

* 1 <u>Bay of Islands</u>	5 Raumati Beach
2 Mahurangi	6 Raglan Harbour
3 Ohiwa Harbour	7 Kaipara Harbour
* 4 <u>Wellington Harbour</u>	8 Dargaville Beach

B. Plankton sampling stations and adult collecting areas in Wellington Harbour.

C. Plankton sampling stations and adult collecting areas in Bay of Islands.

* main plankton sampling areas.

FIG.1

FIG. 2

FIG.3

was the only station in Bay of Islands and Wellington Harbour at which larval abundance appeared to be grossly affected by the tide, although the larval composition did remain much the same over the tidal cycle.

The use of a logarithmic scale in describing seasonal larval abundance, and the use of percentage occurrence graphs showing the relative abundance (Fig.3.58) of the different larval species, places in perspective, and reduces the visual effect of, very high larval densities encountered, for example, on the flood tide at the estuarine Confluence station.

COLLECTION OF LARVAE

(a) Sampling period. In Bay of Islands plankton samples were taken from April 1970 to December 1971 from a 19 foot outboard launch, although from May 1971 a fishing boat was hired to sample outer stations.

In Wellington Harbour, plankton collections were made from May 1970 to February 1972 from M.V. "Tirohia" of the Zoology Department, Victoria University, and from a 14 foot open outboard whaler.

Plankton collections from other areas given in Fig.3.3A were made from various small craft over short periods during 1971-72. The sampling times are given later with the results.

(b) Description of the net. The design of a sampling technique depends upon the specific research problem, and upon the practical considerations of manpower, manoeuvrability, sampling time available etc. In this study I required a collecting device which I could handle without assistance, transport between widely separated sampling locations, and yet which would rapidly and effectively filter water quantitatively. Most quantitative studies on bivalve larvae overseas have made use of plankton pumps (e.g. Carriker, 1951, Wood and Hargis, 1971 etc.) However plankton pumps are cumbersome, and I considered it to be too dangerous to operate a plankton pump from a small boat without assistance. A plankton net of some kind seemed appropriate.

Smith, Counts and Clutter (1968) discussed design criteria for plankton nets, and devised a net (WP_2) that maintained a 85% or more filtering efficiency during tows. Dr. R. B. Pike, the Director of the Victoria University Island Bay Marine Laboratory, arranged the construction of a net of this design, but modified to a free-fall version. It was tested and found to quantitatively catch larger zooplankton from Cook Strait. Dr. Pike suggested that a version of this net with a much finer mesh would be suitable for the present study.

Bartle (1972) presented a very thorough review of the basic WP_2 free-fall net design and use, and only the broadest aspects are now discussed.

To maintain a high filtration efficiency, Smith, Counts and Clutter (1968) found that net design was crucial. They found that a combination cone-cylinder net was more efficient than either a cone or a cylinder, and that sustained filtering efficiency depended mainly on the mesh size and the filtering area. The clogging rate was found to be roughly an inverse linear function of the individual mesh aperture area if all other net dimensions were constant. They suggested that before the ratio of the filtering area to mouth area (R) was determined, an estimate had to be made of the volume of water to be filtered, and the clogging likely to be encountered. For "green water", they presented the following relationship:

$$\log_{10} R = 0.38 \log_{10} \left(\frac{V}{A} \right) - 0.17$$

R = ratio of filtering area to mouth area

A = mouth area of net in m^2

V = volume of water filtered in m^3

The mesh size is determined by the size of the organisms. All late stage bivalve encountered in preliminary observations in both harbours exceeded 200 μ in length, and most D-shaped larvae exceeded 100 μ . Since only late stage larvae were required for this study,

(although an estimate of D-shaped larvae was also to be made), a 100 μ mesh size was considered to be adequate. The diameter of the mouth of the net was 0.5 m.

$$\text{Required volume of water} = \pi r^2 h$$

where h is the drop length.

The maximum drop envisaged was 100m, although drops of this length were seldom used.

$$\pi r^2 h = 19.6 \text{ m}^3$$

$$\therefore \log_{10} R = 0.38 \quad \log_{10} \left(\frac{19.6}{0.2} \right) = 0.17$$

$$R = 3.9$$

Porosity of 0.1 mm. monyl bolting silk = 0.39

$$\begin{aligned} \text{Combined area of mesh panels} &= 0.2 \times \frac{3.9}{0.39} \\ &= 2.00 \text{ m}^2. \end{aligned}$$

The net finally constructed had a greater combined mesh panel than this (3.14 m²). Although this was not intended, it was fortuitous since in estuarine areas the net was much more prone to clogging by silt and phytoplankton than in the clear California current waters in which Smith, Counts and Clutter (1968) made their tests.

The net is shown in Fig.3.4. The galvanised iron ring at the mouth of the net weighed 7 kilograms, and was sufficiently heavy to drag the net through the vertical water column. A rapid drop was not required since bivalve larvae are incapable of rapid avoidance reactions; Wood & Hargis (1971) calculated that the most rapid rate of movement of oyster larvae was about 1cm/sec. The net was attached to the metal ring by a canvas collar, around which the throttling rope ran. The truncate cone had a mesh area of 1.36 m², while the cylinder had a mesh area of 1.78 m². The truncate cone terminated in a bucket at the end of which a 100 μ mesh silk filtered the plankton sample.

FIG.3.4.

WP₂ FREE FALL NET

Dimensions in centimetres.

GR = galvanised ring

TR = throttling rope

CC = canvas collar

C = cylinder

)

) mesh size 100 μ

TC = truncate cone

)

)

)

Using a net of similar design, Smith, Counts and Cutter (1968) had better than 95% filtering efficiency in over 2,000 hauls in the California current at all seasons. They considered their net to be clogged when the filtering efficiency was below 85%. With the added filtering area of the net used in this study, initial filtration efficiency would have been better than 95%, and a filtering efficiency of better than 85% would always be expected during the sampling programme.

(c) Operation of the net.

The net was carefully released in the open position at the water surface and the throttle rope allowed to run freely out. On reaching the pre-selected depth, the recovery line was checked, thus throttling the net. The throttled net was hauled to the surface, and jugged up and down as it neared the surface, to make sure the plankton had moved down the net into the collecting bucket. The retaining silk on the bucket was removed, and the plankton carefully washed into an Agee jar of salt water.

Plankton samples were preserved within 2 hours of collection in a seawater solution of 10% sugar and 1% formalin neutralised with sodium bicarbonate (Carriker, 1950).

LABORATORY PROCEDURES

The bivalve larvae were isolated by swirling the plankton sample in a round bowl, and were then pipetted onto a gridded stage. The number of each late stage larval species, as well as an estimate of the total number of D-shaped larvae, were recorded for each grid square, and totals for the sample obtained. The whole sample was analysed where possible, but sometimes the large number of larvae made subsampling necessary.

Because of the small size of bivalve larvae, it was decided that the most efficient subsampling technique would be the one involving the

least manipulation of the larvae. Of the methods available, that of taking aliquots from an agitated measuring cylinder (Brinton, 1962) appeared the simplest and most satisfactory. Samples were halved or quartered by this method, and the larval numbers extrapolated for the whole sample.

Greater accuracy in the subsampling may have been attained using subsamplers such as the Folsom Splitter, or the Whirling Sub sampler (Kott, 1953) etc. but the simplicity of the agitated measuring cylinder technique eliminated the problem of larvae being caught unnoticed in the compartments and corners of the subsampling device.

DESCRIPTION AND IDENTIFICATION OF LATE STAGE BIVALVE LARVAE	IN THIS STUDY
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Larval descriptions are based on larval shell dimensions, shape, colour, texture, hinge characters, and the presence of other features such as byssal notch, eyespot etc. Larval dimensions given are based on observations on at least 20 larvae of each species. Photomicrographs are of well preserved whole larvae from the plankton samples, or of single valves (separated by placing the larvae in 10% sodium hypochloride for 10 minutes).

Larval hinges were photographed after allowing the valves to just separate in 10% sodium hypochlorite solution (Rees, 1950). An adjusted polarised light source was used to accentuate hinge features, but none of the results are as satisfactory as those obtained by scanning electron microscopy (Scholtema, 1971 and Robertson, 1971). Unfortunately no scan electron microscope was available for this study.

Few attempts are made to describe D-shaped larvae because of their great similarities, except in the case of incubatory species, in which the D-shaped larvae can be obtained from the parent.

All identifications of non-incubatory bivalves in this study are based on indirect methods, since attempts at laboratory rearing were

unsuccessful (described previously). Larvae are identified to superfamily level according to the hinge classification of Rees (1950), and then larval abundance is related to adult abundance in the area. In some cases, the larval occurrence in the plankton is related to the adult gonad condition or reproductive cycle. In other cases, early postlarval forms showing the prodissoconch 2 shell are used to substantiate the identification. Larval shapes are also compared to previous published descriptions of larvae of the same genus elsewhere.

Clearly, the provisional identifications made by these indirect methods require verification by direct, laboratory-culture techniques.

The identification of the larvae of incubatory species up to the time of release is positive. Sometimes it is then simple to follow the later planktonic development of larval characteristics which have by then become apparent.

DETERMINATION OF SPAWNING CYCLES

(a) Histological Techniques.

Indications of the stage of gonad development were obtained by a rapid embedding/sectioning/staining method. The gonad was embedded in gelatine (according to the schedule in Table 3.2) and a section 1 mm. thick was cut from the centre with a sharp razor, and stained for 45 minutes in Heidenheins Iron haematoxylin.

Gonad stages were divided into four categories:

- 1 - More than 75% spawned. (evacuated)
- 2 - Developing, indeterminate gonad.
- 3 - Developing sperm or eggs.
- 4 - Ripe sperm or eggs.

Fig 3.5 gives examples of some of these categories.

TABLE 3.2

Gelatine Embedding Schedule

1% gelatine	1 - 2 days	)	@ 38°C
		)	
5% gelatine	1 - 2 days	)	
		)	
10% gelatine	1 - 2 days	)	
		)	
20% gelatine	1 - 2 days	)	

Embed gonad in 20% gelatine at room temperature, allow to set, harden and store block in 10% formalin.

(b) Incubatory species.

40 - 50 individuals of similar size were opened monthly, and the number of larvae in the brood chamber counted, or assessed, and at least 6 measured to determine the average larval size.

(c) Condition index.

Three methods were used for formalin-preserved animals. Generally 25 animals of similar size were measured monthly in 5 groups of 5.

(i) Wet weight condition index.

Animals were thoroughly cleaned of encrusting growth and opened. Byssal threads were removed from Mytilids. The flesh of 5 individuals were removed from the shells, washed, and the shells and flesh separately drained for a standard time (15 minutes) on filter paper, and then weighed.

$$\text{Condition index} = \frac{\text{weight of flesh in grams}}{\text{weight of flesh and shell in grams}} \times 100$$

(ii) Dry weight condition index I

The same procedure as above, except the flesh was dried at 60°C for 48 hours.

$$\text{Condition index} = \frac{\text{weight of dried flesh in grams}}{\text{weight of dried flesh and shell in grams}} \times 100$$

(iii) Dry weight condition Index II

Five firmly-closed animals were placed in a displacement jar of the type described by Baird (1957), except that the outlet was approximately 2cm. from the top of the jar, and the volume of water displaced by the animals recorded. The animals were then opened, and the volume of water displaced by the 5 pairs of valves alone was determined. The flesh of the 5 animals was then washed and dried at 60°C. for 48 hours.

$$\text{Condition index} = \frac{\text{weight of dried flesh in grams}}{\text{shell cavity in ml.}} \times 1000$$

Although Baird (1957) considered little accuracy was to be gained in using dryweights for the determination of condition index, Walne (1970) considered that the use of dry weights avoids the difficulties involved in standardizing the method of removing and measuring wet weights, and also eliminates the problem of meat containing variable amounts of water that may obscure fluctuations in condition.

In this study, dry weight condition index I was sometimes determined in addition to wet weight condition index (in Fig.3.13), and the two curves usually correlated closely.

Several workers have found intraspecific differences between high and low members of populations of intertidal invertebrates. Segal, Rao and James (1953) noted variations in the physiology and wet weight of the soft-parts of Acmaea scaba and in the physiology of Mytilus californianus, of individuals from different intertidal heights. Medcof and Needler (1941) found that the condition of oysters varied with size, shell shape and the depth of water from which they were taken. Baird and Drinnan (1956) found that mussels periodically exposed to air had a higher ratio of shell to meat than mussels ^{not} exposed to air. Westley (1964) found that the condition of oysters (Crassostrea gigas) varied considerably between areas of differing nutrient supply.

For these reasons, animals of a species required for condition index analyses were always taken from the same locality and from the same tidal level.

FIG.35. EXAMPLES OF GELATINE-EMBEDDED GONADS.

1. Developing sperm in Chione stutchburyi
2. Ripe sperm in Chione stutchburyi
3. Ripe eggs in Chione stutchburyi
4. Partially spawned egg follicles in Macomona liliana
5. Ripe eggs in Macomona liliana
6. Ripe sperm in Macomona liliana

FIG. 5

1

2

3

4

5

6

Animals of approximately the same size range were always used, as Baird (1957) advised.

Unfortunately it was not possible to make the condition analyses on live animals. The shellfish were fixed in approximately 15% formalin/seawater, and stored in 5% formalin/seawater, until the condition index was determined. Since the delay between the collection of the shellfish and the determination of the condition index was approximately the same throughout the sampling period, errors due to the technique are constant.

PRESENTATION OF RESULTS

Each common pelagic late stage bivalve larva encountered in the plankton samples is classified to the superfamily level by means of its hinge structure (after Rees, 1950). The larvae of each superfamily are grouped together, and provisional identification to genus or species is made, based on the methods already outlined. Larvae that could not be classified to a superfamily by their hinge structures appear in a separate group at the end. Brooding species are included in their respective superfamily grouping.

Bivalve classification is according to Morton (1967) and Powell (1961), unless stated otherwise.

Each larval species is described by a photomicrograph, usually of a group of larvae of the species. Often photomicrographs of a single valve of the species are also included, so that larval shapes can be compared to those of Rees (1950). Larval measurements are in microns (μ). Hinge line lengths are the lengths between the margins of the shell at the position of the hinge. Hinge photographs could not be included with their respective larva because of plate-making difficulties. Instead they are grouped in superfamilies, and appear after the larvae of each superfamily.

The seasonal occurrence of members of each superfamily at Bay of Islands and Wellington Harbour appear after the hinge photographs. The scale is such that if 1 is added to each value, the points then fall on a log scale.

This gives the log scale a zero point and also reduces the visual significance of low values.

The occurrence of larvae at Raumatī Beach for 1970-72 are given in Table 3.3, at Dargaville Beach for 1969/70 in Table 3.4, and at some northern harbours for Spring 1971 in Table 3.5.

Reference is continually made to the distribution and abundance of the bivalve adults at each locality (Tables 2.5, 2.9 and 2.10., Beu and Climo, 1971, and Wellington Shell Club, 1969). Caution must be exercised in relating the abundance of the adults of a species to the expected abundance of its larvae, since variations in annual spawning intensities and settlements in invertebrates are widely reported (Sears and Clarke, 1940, Coe, 1953, Barnes, 1956 etc.)

Seawater temperature data are taken from the tables of average surface sea temperatures for Bay of Islands in Table 1.3 and Wellington Harbour in Table 1.9.

Larval abundance in Bay of Islands and Wellington Harbour is assessed as follows:

- abundant - larval densities > 100 larvae/1000 litres seawater.
- common - larval densities 10-100 larvae/1000 litres of seawater.
- frequent - larval densities > 1 , but < 10 larvae/1000 litres of seawater.
- occasional - larval densities < 1 larva/1000 litres of seawater.

Larval abundance of particular species at the other sampling areas is assessed relative to the total density of bivalve larvae present.

Seasons of the year are defined as the following:

- winter = June, July, August
- spring = September, October, November
- summer = December, January, February
- autumn = March, April, May.

TABLE 3.3. Seasonal abundance of some bivalve larvae at
Raumati Beach (see Fig 3.3A)

The observations are based on two WP₂ net drops 500m off the beach,
and two net tows 100m off the beach.

Abundance of individual larval species is estimated relative to the total
density of late stage bivalve larvae present. (MC = most common.
Temperatures are the average of four readings. C = common)

<u>DATE</u>	<u>TEMPERATURE</u> (°C).	<u>MOST ABUNDANT LATE STAGE LARVAL FORMS.</u>	
26/11/70	19.0	MC	Mytilid 1, Mytilid 3, <u>Kellia cycladiformis</u> .
12/12/70	21.0	MC	Mytilid 4, <u>Kellia cycladiformis</u> , ? <u>Arthritica bifurca</u> .
17/6/71	12.3	MC	Mytilid 2, Mytilid 3, Unidentified larva 1.
		C	Mytilid 4, <u>Kellia cycladiformis</u> , Pholad 1.
25/7/71	12.5	MC	Mytilid 3, Pectinid 1, Unidentified larva 1
		C	<u>Kellia cycladiformis</u> .
30/9/71	13.8	MC	Mytilid 3, Mytilid 4, Unidentified larva 1.
4/11/71	15.9	MC	Mytilid 4.
15/12/71	19.2	MC	Mytilid 1, Mytilid 3, Mytilid 4, <u>Kellia cycladiformis</u> , ? <u>Arthritica bifurca</u> . Mactracean 2, Unidentified larva 1.
17/1/72	19.6	MC	Mytilid 4, <u>Kellia cycladiformis</u> .
		C	Unidentified larva 1.
15/2/72	17.5	MC	Mytilid 2, Mytilid 4, <u>Kellia cycladiformis</u> ? <u>Arthritica bifurca</u> , Mactracean 2.
		C	Mytilid 3, Pectinid 1, Pholad 1, Unidentified larva 1.
15/4/72	16.2	MC	Mytilid 4, <u>Kellia cycladiformis</u> .
		C	Mytilid 1, Mytilid 2, ? <u>Arthritica bifurca</u> .
14/6/72	12.8	MC	Mytilid 4, <u>Kellia cycladiformis</u> , ? <u>Arthritica bifurca</u> .
		C	Mytilid 2, Mytilid 3, Unidentified larva 1.

TABLE 3.4.Some late stage bivalve larvaefrom Dargaville Beach.

(Fig.3.3A)

3 min. surf : tows

<u>Date</u>	<u>Most abundant late stage bivalve larvae</u>
12.12.69	Mytilid 4
20.12.69	Mytilid 4
14.12.69	? <u>Arthritica bifurca</u>
13.1.70	Few larvae
20.3.70	Few larvae
2.12.70	? <u>Arthritica bifurca</u> , Mytilid 2.
12.12.70	Mytilid 2, Mytilid 4, ? <u>Arthritica bifurca</u>

TABLE 3.5. Spring occurrence of some common bivalve larvae
at some Northern Harbours

(for locations see Fig.3.3A)

Plankton samples were usually obtained by surface net tows of approximately 3 minutes duration.

* Most abundant larval species present.
 Not all larval species are recorded.

Date	Raglan Harbour	Kaipara Harbour	Mahurangi	Ohiwa Harbour
17/8/71			Venerid 1 *	
			Macracean 1 *	
22/8/71			Venerid 1	
			Macracean 1 *	
31/8/71			Mytilid 4 *	
			Macracean 1 *	
7-8/9/71	Mytilids 3 & 4 ? <u>Arthritica</u> <u>bifurca.</u> Macracean 1*	Mytilids 3 & 4 ? <u>Arthritica</u> <u>bifurca</u> *	Mytilids 3* & 4 ? <u>Arthritica</u> <u>bifurca.</u> <u>Kellia cycla-</u> <u>diformis</u> Venerid 1 Macracean 1* & 3 ? Larva 1.	
15/9/71			Macracean 1*	Mytilid 3 Venerid 1 Macracean 1*
23/9/71			Mytilids 3* & 1 ? <u>Arthritica</u> <u>bifurca</u> Macracean 1*	

TABLE 3.5 (contd.) Spring occurrence of some common bivalve larvae at Northern Harbours

Date	Raglan Harbour	Kaipara Harbour	Mahurangi	Ohiwa Harbour
30/9/71			Mytilid 4 Mactracean 1*	
6/10/71			Mactracean 1*	
19-21/10/71	Mytilids 3*, 4 & 5 ? <u>Arthritica</u> <u>bifurca</u> Venerid 1 Mactracean 1* ? Larva 1	? <u>Arthritica</u> <u>bifurca</u> Mactracean 1* ? Leptonacean 1.	Mytilids 3,4 & 5* ? <u>Arthritica</u> <u>bifurca</u> Venerid 1 Mactraceans 1* & 3 ? Larva 1	Mytilids 3* & 5 ? <u>Arthritica</u> <u>bifurca</u> Venerid 1 Mactracean 1*
30/11/71				Mactracean 3*
1/12/71		NIL	NIL	
28/12/71		Mactracean 3		
7-8/1/72		NIL	Mytilids 3, 4 & 5*. <u>Ostrea</u> sp. <u>Kellia cycladi-</u> <u>diformis</u> ? <u>Arthritica</u> <u>bifurca</u> * Venerid 1 Venerid 2 Mactracean 1*	Mytilid 4 ? <u>Arthritica</u> <u>bifurca</u> Mactracean 1.
19/1/72		Mytilid 3 ? <u>Arthritica</u> <u>bifurca</u> * Mactracean 1	Mytilid 5 ? <u>Arthritica</u> <u>bifurca</u> <u>Kellia cycladi-</u> <u>formis</u> Mactracean 1	

TABLE 3.5 (contd.) Spring occurrence of some common bivalve larvae
at Northern Harbours

Date	Raglan Harbour	Kaipara Harbour	Mahurangi	Ohiwa Harbour
27/1/72		<u>Crassostrea</u> <u>glomerata</u> ? <u>Arthritica</u> <u>bifurca</u> Venerid 1 Mactracean 3*	Mytilid 5 <u>Ostrea</u> sp. ? <u>Arthritica</u> <u>bifurca</u> Mactracean 1*	
4-5/2/ 72		Mytilids 3 & 5. ? <u>Arthritica</u> <u>bifurca</u> * Mactracean 1*		? <u>Arthritica</u> <u>bifurca</u> Mactracean 1

SUPERFAMILY MYTILACEA

- I. Adult Distribution. (refer to Tables 2.5, 2.9 and 2.10, Beu and Climo, 1971 and Wellington Shell Club, 1969).

The Mytilidae are represented in New Zealand by ten genera and 12 species (Powell, 1961), the most abundant being:

Mytilus edulis aoteanus Powell, an intertidal "distinctively southern species", is found in a few northern localities and continuously from Wellington area south (Morton & Miller, 1968). It occurs mainly in sheltered areas, but sometimes as isolated patches on open shores.

Perna canaliculus (Gmelin) is typically a bivalve of lower shore and open coasts occurring throughout New Zealand (Morton & Miller, 1968), but it also occurs in some sheltered waters.

Aulacomya maoriana (Iredale) is a southern species occurring at LWN or below and is recorded only occasionally north of Castlepoint (Morton & Miller, 1968).

Modiolus areolatus (Gould) occurs at low tide or below, mainly under stones, but is not universally common in New Zealand.

Xenostrobus securis (Lamarck) is the estuarine counterpart of Xenostrobus pulex and extends up estuaries as far as the tidal influence. It is not universally common in New Zealand.

Xenostrobus pulex (Lamarck) an Australasian species widespread throughout New Zealand, occurs mainly in the upper midlittoral zone in open areas, including sandy coasts, and less commonly in harbours.

Modiolarca impacta (Hermann) occurs throughout New Zealand, although not abundantly, at ELW and beyond.

The occurrence of these species in Bay of Islands was given in Tables 2.5 and 2.9. Modiolarca impacta is probably more abundant than the surveys indicated, since it nestles amongst low tide and subtidal rocks, and is not easily taken with grabs.

The occurrence of these species in Wellington Harbour was given in Table 2.10. Xenostrobus pulex is abundant north and south of Wellington, but is scarce in the Wellington region; Morton & Miller (1968) recorded it as being sparse in the harbour, and Flaws (1968) recorded it more commonly on exposed eastern shores and at the harbour approaches. Xenostrobus securis does not occur in Wellington Harbour.

Open sandy areas (Raumati and Dargaville Beaches) have isolated patches of Mytilus edulus aoteanus and large beds of Perna canaliculus and Xenostrobus pulex. Mr. D.E.Flaws (pers.com.) reports large beds of Modiolus areolatus south of Kapiti Island off Raumati Beach. Wellington Shell Club Bulletin (1969) also includes Aulacomya maoriana, Xenostrobus pulex and Modiolarca impacta on Wellington West Coast beaches.

II. Larval features:

Chanley (1970) reviewed the literature on Mytilidae larval characteristics. The main features of pelagic larvae of the Mytilidae include: (Summarised from Chanley) -

1. Hinge line is long compared with other dimensions and increases in length with larval growth.
2. Dentition consists of a series of taxodont teeth over the entire hinge line but with larger teeth near the ends.
3. The umbo is usually late in development and remains low, rounded and inconspicuous (although it is more pronounced in the genus Modiolus).
4. The anterior end is rounded but not nearly as blunt as the posterior, thus giving an "egg-shape".
5. The colour is usually dark or some shade of brown.
6. The larvae attain a comparatively large pelagic size (often greater than 300 μ) although there may be much variation in settling size among larvae in the same species.

Rees (1950) detailed the hinge structure of the Mytilacea. The hinge structure closely resembles that of the Pectinacea and Anomiacea, except that the region between the two most thickened parts of the provinculum is still significant and bears teeth.

Mytilidae also frequently have prominent eyespots in the late stage larvae and pediveliger e.g. Mytilus crassitesta (Miyazaki, 1935 and Yoshida, 1953), Mytilus edulis and Modiolaria marmorata (Jorgensen, 1946) Modiolus demissus (Loosanoff, Davis and Chanley, 1966 and Chanley and Andrews, 1971), Lithophage bisulcata (Culliney, 1971) etc.

III. Common New Zealand Mytilid larvae:

Five species of late stage bivalve larva occurring in the plankton samples have been placed in the Mytilidae on their hinges and larval features.

MYTILID 1 ? Mytilus edulis aoteanus Powell

A. Description - (Figs. 3.6 and 3.11).

The larval shape most closely fits the Rochefortia grouping of Sullivan (1948) and the Mytilidae grouping of Miyazaki (1962); both of these include Mytilus edulis.

The late stage larval hinge is typically Mytilacean, and the hinges of both valves are almost identical. (Fig. 3.11 shows the larval hinge of the left valve). The hinge has a thickened provinculum with 6 to 8 teeth on each end, a reduced region between, and no lateral hinge system. The hinge teeth are not well developed. Chanley and Andrews (1971) also noted poorly developed hinge teeth in Mytilus edulis larvae. The late stage eyed larva usually reaches 275 μ in length, with a height of about 250 μ and a hinge line of approximately 100 μ in length. Younger umbo larvae prior to the development of the eyespot have a similar length-height relationship.

In the late stage larva the umbos are knobby to broadly rounded, and are equal in size. The anterior end is much more pointed and slightly longer than the posterior, and the posterior shoulder is more

rounded than the anterior shoulder. The ventral margin is rounded.

The larva is dark or dark yellow and sometimes has a purple or brown tinge around the umbos. A prominent eyespot (5 - 7 μ across) appears in larvae approximately 230 μ or more in length (Fig. 3.6b).

Marked concentric lamellae are visible in the outer prodissoconch 2 shell under polarised light, but there are no radial striae. Prodissoconch 1 shell is generally not clearly delineated from the remainder of the larval shell. The prodissoconch 2 shell shape is seen in the Mytilus edulis aoteanus postlarvae (Figs. 3.6c and 3.6d), obtained from adult Mytilus edulis aoteanus beds in Wellington Harbour.

This larva closely resembles illustrations and dimensions of Mytilus edulis larvae (photomicrographs of T.C. Nelson, 1928, line drawings of Borisjak, 1909, Werner, 1939 and Jorgensen, 1946, photomicrograph 5, plate VII of Sullivan, 1948, and photomicrograph of larvae at 296 x 282 μ of Loosanoff, Davis and Chanley, 1966), and is similar to the photomicrographs of Chanley and Andrews (1971) and Rees (1950) of ^{this} larval species.

B. Larval distribution - Figs. 3.12 and 3.58

Tables 3.3, 3.4 and 3.5

Refer to adult abundance Tables 2.9 and 2.10, and Wellington Shell Club, (1969).

This larval species was often abundant at all of ^{the} Wellington Harbour plankton stations. Mytilus edulis aoteanus adults are also abundant in Wellington Harbour.

This larva occurred frequently in Bay of Islands, where Mytilus edulis aoteanus adults are less abundant than in Wellington Harbour. The larva occurred in highest densities at the inner harbour stations (Confluence and Brampton Reef).

This larva occurred quite frequently at Raumati Beach, but the few summer plankton samples from Dargaville Beach contained none.

In general, the planktonic abundance and distribution of this larva correlates well with the abundance and distribution of the adults

of Mytilus edulis aoteanus.

C. Seasonal abundance - Figs.3.12 and 3.58.

Tables 3.3, 3.4 and 3.5.

In Wellington Harbour, this larva occurred in the plankton throughout much of the year, with peaks at all plankton stations in early spring (1970 and 1971), early summer (1970-71, and possibly 1971-72) and late autumn (1971). Although spawning occurred over the winters of both years, there was a drop in intensity during the coldest months (June and July), particularly in 1970.

Fig.3.13 gives the monthly wet and dry weight I condition index cycles (see Section 3, Methods) for Mytilus edulis aoteanus from Karaka Bay, Wellington Harbour, for 1971 - 2. There appeared to be a fairly close correlation between larval abundance in the plankton and the condition cycle of the adult stock. The spawning peak in late December 1970 was followed by a rise in condition, reaching a peak in April. This peak in condition occurred almost two months after the highest water temperature in the harbour. The rapid drop in condition during April and May 1971, when the water temperature was between 15° and 17°C, coincided with the main peaks of the late autumn spawning in 1971. The condition index fell during the winter, and also during the early spring spawnings, when the water temperature was between 11° and 12°C. The improvement in condition of Mytilus edulis aoteanus began in September, 1971, which was again two months after the spring increase in sea temperature. Peak condition was reached in November 1971, and at that time few larvae occurred in the plankton samples. The spawning in November 1971, when water temperatures were between 15° and 17°C, coincided with a drop in the condition of the adults in December 1971.

The monthly wet weight condition index for Mytilus edulis aoteanus from Wairoa Bay, Bay of Islands, for 1970-72 also appears in Fig.3.13. The maximum and minimum condition index preceded the maximum and minimum water temperatures by approximately one month in 1971. The curve

suggests spawnings during September 1970 (?), January-February 1971, and September 1971. The larval densities in the plankton were too small for significant correlations to be apparent between them and the adult stock condition, but peak larval densities did occur during September-October at water temperatures of 15° - 16° C of both years, with smaller spawnings occurring throughout much of the year except mid-summer.

Larvae of this species occurred at Raumati Beach in late spring and early summer 1970, early summer 1971, and autumn 1971, with no evidence of a winter spawning.

In summary, this species appears to spawn at different months in different localities, but with peak spawning in spring and late autumn, and only trickle spawning over mid-summer. These times are not, however consistent with the spawning periods given by Ralph and Hurley (1952) and MacDonald (1963), but their information is not derived from larval occurrence (see Table 3.1). The sampling period of Colgate (1971) is too short to be directly compared.

The condition cycles of adults at Bay of Islands and Wellington Harbour appeared to follow the general water temperature curves, but were not entirely dependent on them. Adults at Bay of Islands had a lower overall condition index during 1970-71, and also showed greater variation in monthly condition than adults in Wellington Harbour.

MYTILID 2.

? Modiolus areolatus (Gould)

A. Description - (Figs.3.7 and 3.11).

The shape of this larva has little similarity to the Mytilidae grouping of Miyazaki (1962), but the larva does have several Mytilid features.

The late stage larval hinge (Fig.3.11, both valves) is typically Mytilacean, with a well-developed taxodont provinculum with 6 - 7 provincular teeth at each thickened end, and reduced dentition between.

There is no lateral hinge system.

The eyed late stage larva often reaches 325 μ in length, with a height of about 275 μ and a hinge line of 130 μ .

The umbos are knobby, equal in size, and more conspicuous than in Mytilid 1 larvae. The anterior end is much more pointed and a little shorter than the posterior end. The posterior shoulder is more rounded and higher than the anterior shoulder. The ventral margin is almost flat.

The larva is distinctly yellow throughout, and a pigmented eyespot, approximately central and 4-6 μ across, appears in larvae about 250 μ or more in length. The umbo region has a purplish or red-brown tinge.

The valves and hinge structures are heavy and strong. Fine concentric lamellae over the valves are seen under polarised light, but there are no prominent radial striae. The prodissoconch 1 shell is not clearly marked off from the prodissoconch 2 shell, although more punctate sculpturing is apparent in the outer prodissoconch 2 shell under polarised light.

This larva mostly resembles the larva of Modiolus demissus at 303 x 260 μ given by Sullivan (1948) and in Fig.10K of Loosanoff, Davis and Chanley (1966), and Lithophaga bisulcata larvae at 409 μ (Fig.7) given by Culliney (1971).

B. Larval distribution and seasonal abundance -

Figs.3.12.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance tables 2.9 and 2.10 and Wellington Shell Club (1969).

This larva occurred very occasionally in Wellington Harbour plankton, mainly during autumn and winter. It occurred frequently in Bay of Islands at all three plankton stations, but in greatest densities in the more open water, Waewaetoria station. Peak larval occurrences

in the plankton were during the midwinter and spring of both years, and also during the midsummer of 1971.

This larva occurred most abundantly at Raumati Beach, and in greatest densities during March (late summer) 1972, but also during June (winter) 1971 and 1972, and February (summer) 1972.

The Mytilid species whose adult distribution and abundance is most consistent with these larval occurrences is Modiolus areolatus. There are large beds of adults of this species south of Kapiti Island, offshore from Raumati Beach (Flaws - pers.com.) Adults of this species also occur frequently in Bay of Islands, but are uncommon in Wellington Harbour.

Spawning peaks at all three localities were during the summer and winter, but also during late spring in Bay of Islands.

MYTILID 3. ? Perna canaliculus (Gmelin)

A. Description - (Figs 3.8 and 3.11).

The larval shape most closely fits the Mytilidae grouping of Miyazaki (1962).

The late stage larval hinge is typically Mytilicean and the hinge of the right valve is almost identical to that of the left. (Fig.3.11 gives the hinge of the right valve). There is a thickened provinculum with 5-6 teeth on each end, and a reduced region between. There is no lateral hinge system.

The late stage larvae usually reach 300 μ length, with a height of 275 μ and a hinge line length of about 100 μ .

In the late stage larva the umbos are more knobby than in Mytilid 1, and are equal in size. The anterior end is more pointed than the posterior end, (but not as pointed as in Mytilid 1), and is sometimes slightly shorter. The larva is higher than Mytilid 1,

but of similar depth. The short straight posterior and anterior shoulders are of similar height, and the ventral margin is more circular than Mytilid 1 because of the greater height.

The larva is darkish in colour, and may have a purplish tinge around the umbos. A prominent eyespot appears in larvae of approximately 250 μ length.

Fine concentric lamellae in both prodissoconch shells are visible under polarised light (Fig.3.8d), and the prodissoconch 1 shell is generally quite clearly delineated from the prodissoconch 2 shell.

The prodissoconch 2 shell shape is clearly seen in an early dissoconch shell of Perna canaliculus (Fig.3.8b) taken from adult Perna beds in Wellington Harbour.

This larva does not closely resemble any published larval descriptions I have seen.

B. Larval distribution - Figs.3.12 and 3.58.

Tables 3.3, 3.4 and 3.5

Refer to adult abundance Tables 2.9 and 2.10, and Wellington Shell Club (1969).

This larva occurred most commonly in the Wellington Harbour plankton, and less frequently at Bay of Islands, Raumati Beach and Dargaville Beach, and at the four northern harbours in Table 3.5.

In Wellington Harbour it occurred commonly at all plankton stations, but least commonly at the Petone Beach station. In Bay of Islands, the larva occurred most commonly at the outer harbour plankton station (Waewaetoria).

This larval distribution and abundance is most consistent with the distribution and abundance of the adults of Perna canaliculus.

C. Seasonal abundance - Figs.3.12 and 3.58.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands peak larval occurrences in the plankton were during the spring of both years, but very small numbers did occur at other times of the year.

Fig.3.13 gives the monthly wet weight condition index of Perna canaliculus adult stock at Wairoa Bay, Bay of Islands (Fig.3.3C) during 1970-71. The condition index cycle of the adults broadly followed the water temperature pattern, although the condition index reached its maximum three months after the water temperature in 1971. A marked drop in condition occurred during the midwinter of 1971, but this occurred too early to be consistent with the spring peak of larvae in the plankton in the same year.

In Wellington Harbour peak larval occurrences in the plankton were during the summer, midwinter and spring of both years. The monthly condition index cycles (wet weight and dry weight I) are given in Fig.3.13 for adult Perna canaliculus from Karaka Bay in Wellington Harbour, (Fig.3.3.B) during 1971. Both condition index cycles have a similar curve, although the dryweight curve has a greater amplitude, and both broadly follow the water temperature curve. The peak in the condition index cycle occurred about one month after the maximum water temperature in February 1971, and about two months before the maximum water temperature in January 1972.

Except for the sudden decline in condition of the adults during May - June 1971, which was consistent with larval occurrences in the plankton about that time, there is little correlation between the condition cycle of the adults and the occurrence of larvae in the plankton.

At Raumati Beach this larva occurred in the plankton throughout much of the year, except during the autumn. It occurred in the summer plankton samples at Dargaville Beach, and in spring plankton samples at Raglan, Mahurangi and Ohiwa Harbour, and spring and summer plankton samples at Kaipara Harbour.

The consistent features in the occurrence of this larva in the plankton at these locations is the continuity of spawning throughout much of the year except autumn, and the presence of peaks in larval occurrence during the spring and summer. The spring and summer maxima are consistent with the settlement of Perna canaliculus spat at Te Kouma Harbour during 1967 - 69 (Greenway, 1969b), but are not consistent with the observations of MacDonald (1963) at Lyttleton Harbour. Brunette (1970), making settlement observations during the first half of 1970 at Kenepuru Sound, recorded Perna canaliculus settling during summer.

MYTILID 4. ? Xenostrobus pulex (Lamarck)

A. Description -(Fig.3.9)

The larval shape most closely fits the Teredo group of Sullivan (1948) and Miyazaki (1962), but all features are typically Mytilid. The late stage larval hinge (not pictured) is typically Mytilacean, and almost identical in both valves, with a wide, heavy provinculum with well developed taxodont dentition which is reduced in the centre.

The late stage larvae usually reach 310 μ in length and 325 μ in height, with a hinge line of about 90 μ length. Earlier developmental stages are given in Figs.3.9 c and d.

The umbos are knobby and equal in size. The rounded shoulders are high and almost equal in length, although the anterior end is slightly longer and more pointed. The height and almost circular ventral margin make the larva egg-like (and Teredo-like)

The larva is strong and heavy, and darkish in colour, often with a purplish tinge around the umbos and provinculum. A prominent eyespot (5 - 7 μ across) appears in larvae of approximately 250 μ in length. Quite marked concentric lamellae are seen over the shell under polarised light, but there are usually no radial striae. The prodissoconch 1 shell

is not clearly delineated from the prodissoconch 2 shell.

The prodissoconch 2 shell shape is clearly seen in an early dissoconch shell of Xenostrobus pulex taken from adult beds south of Raumati Beach. (Fig.3.9b).

The late stage larva described by Rapson (1952) as that of Amphidesma ventricosum in Figs. 3, G, H and I (page 177) and Fig.4,G (page 179) is probably Mytilid 4.

The pronounced difference in larval shape between Mytilid 4 (provisionally identified as Xenostrobus pulex) and Modiolus demissus (Sullivan, 1948 and Loosanoff, Davis and Chanley, 1966), and the provisionally identified Modiolus argolatus larva (Mytilid 2), supports the recent removal of Xenostrobus pulex from the genus Modiolus.

B. Larval distribution - Fig.3.12

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance tables 2.9 and 2.10 and Wellington Shell Club (1969).

This larva occurred frequently in plankton samples from Bay of Islands, and occasionally in plankton samples from Wellington Harbour. It was common in Raumati Beach and Dargaville Beach plankton samples, and also occurred in the plankton at Raglan, Kaipara and Ohiwa Harbours, and at Mahurangi.

In Bay of Islands it occurred at all three plankton stations, and in Wellington Harbour only in the open water plankton stations.

This larval distribution and abundance is consistent with that of the adults of Xenostrobus pulex.

C Seasonal abundance - Fig.3.12.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands, this larva occurred in the plankton throughout much of the year, and with peak larval occurrences during the spring.

In Wellington Harbour plankton it was recorded during early winter and spring 1971.

The larva occurred in the plankton throughout much of the year at Raumati Beach.

At Dargaville Beach it was very abundant in the plankton during early summer, and in the northern harbours (Table 3.5) it occurred commonly, often abundantly, during the spring.

The observations suggest that Xenotrobus pulex spawns throughout much of the year, probably with a peak in spring. Xenotrobus pulex is an Australasian species, and Wilson and Hodgkin (1967) recorded the species spawning in late winter (August) and spring to mid-summer (October-January) near Freemantle, Western Australia, during 1961-2. The times of peak spawnings at Freemantle are broadly consistent with the times of peak spawnings found in this study.

MYTILID 5.

? Modiolarca impacta (Hermann)

A. Description - (Figs.3.10 and 3.11)

This larva closely resembles Mytilid 2 (Fig.3.7), and although its shape shows little similarity to the Mytilidae grouping of Miyazaki (1962), its larval features are Mytilid.

The well-developed, typically Mytilid acean late stage larval hinge is almost identical in both valves, (Fig.3.11 shows the left valve), and has a thickened provinculum with 5-6 provincular teeth at each end, and a reduced region between. There is no lateral hinge system.

Late stage planktonic larvae often reach 300 μ in length, with a height of 250 μ and a hinge line length of 110 μ . But the settling length appears to be highly variable, with larvae generally reaching a larger size before settling out of the plankton during colder months.

The umbos are knobby and equal in size. The anterior end is slightly longer and more pointed than the posterior end. The posterior and anterior shoulders are of more similar slope than those of Mytilid 2.

The ventral margin of the Mytilid 5 is more rounded than that of

This strong heavy larva lacks the yellow colouration of Mytilid 2, and generally has a redbrown or purple tinge around the umbos and provinculum. A prominent eyespot, 5 - 7 μ across, appears in larvae of approximately 250 μ or more in length (Fig.3.10c).

Concentric lamellae are visible under polarised light, particularly in the prodissoconch 2 shell. The two prodissoconch shells are generally not clearly delineated.

Early postlarvae of Mytilid 5 taken in plankton samples and from postlarval collecting plates in Wellington Harbour are given in Figs.3.10b and d. Later postlarvae are given in Figs.3.10e,f and g. and show the early development of Modiolarca impacta.

The larva closely resembles the line drawings of Modiolaria marmerata of Jorgensen (1946) (Fig.168).

B. Larval Distribution -

Figs.3.12 and 3.58

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance tables 2.9, 2.10 and Wellington Shell Club (1969).

This species occurred commonly in Bay of Islands plankton at all the plankton stations, particularly those in the inner harbour.

It occurred abundantly in Wellington Harbour plankton at all stations.

It occurred occasionally in Raumati Beach plankton, but was not recorded in the summer plankton samples from Dargaville Beach. It occurred at all northern harbours (Table 3.5), sometimes frequently.

The distribution and abundance of this larva in the plankton is generally consistent with that of the adults of Modiolarca impacta.

C. Seasonal abundance -

Figs.3.12 and 3.58.

Tables 3.3, 3.4 and 3.5.

This larva occurred in Bay of Islands plankton throughout much of the year, except during late autumn, and with peak occurrences during late winter, spring and summer of both years.

In Wellington Harbour this larva occurred in the plankton throughout much of the year, but with peak occurrences during midsummer 1970-71, and late autumn, early winter, and early spring of 1971.

Fig.3.13 gives the monthly wet weight and dry weight I condition indices for Modiolarca impacta adult stock from Mahanga Bay, Wellington Harbour (Fig.3.3B) during 1971. Also given in Fig.3.13 is an estimate of the mean relative mantle gonad thickness of the adults.

The condition index and gonad thickness curves for the adults from Wellington Harbour are similar, and are approximately inversely related to the water temperature, with maximum condition occurring at the time of minimum water temperature. The curves suggest spawnings during December - January 1970-71 and 1971-72, and during spring (August - September) 1971. These are in general agreement with the occurrences of Mytilid 5 larvae in the plankton. Small spring and summer occurrences of this larva in the plankton were recorded in the four northern harbours. (Table3.5.)

In summary, Modiolarca impacta appears to spawn throughout most of the year at Bay of Islands and Wellington Harbour, with peak and minimal larval densities occurring in the plankton at different times of the year at each harbour.

FIG.3.6.

MYTILID 1.

? Mytilus edulis aoteanus Powell

- (a) Group of eyed late stage larvae.
(average length 275 μ)
- (b) Late stage larva (275 μ length) showing eyespot.
- (c) Early postlarva (dissococonch) showing prodissococonch 2 shell shape.
- (d) Later postlarva.

MYTILID 2

? Modiolus areolatus (Gould)

- (a) Group of eyed late stage larvae
(average length 325 μ)
- (b) Pair of single valves (upper, left valve, 310 μ length;
lower, right valve 330 μ length)

a

b

c

d

a

b

FIG.3.8

MYTILID 3

? Perna canaliculus (Gmelin)

- (a) Group of eyed late stage larvae,
(average length 295 μ)
- (b) Early postlarva (dissococonch) showing prodissococonch 2 shell
shape. (310 μ length)
- (c) Early umbo larva (180 μ length)
- (d) Single valve (left) of late stage larva showing
concentric lamellae. (290 μ length)

FIG.3.9

MYTILID 4.

? Xenostrobus pulex (Lamarck)

- (a) Group of eyed late stage larvae
(average length 300 μ)
- (b) Early postlarva (dissococonch) showing prodissococonch 2 shell
shape. (420 μ length).
- (c) and (d) Early umbo larvae (180 and 220 μ length, respectively)
- (e) Single valves (right and left) of late stage larva.
(295 μ length)

a

b

c

d

a

b

c

d

e

FIG.3.10

MYTILID 5.

? Modiolarca impacta (Herman)

- (a) Group of eyed late stage larvae
(average length 290 μ)
- (b) Group of early postlarvae (dissoconch)
(average length 425 μ).
- (c) Late stage larva showing prominent eyespot.
(285 μ length)
- (d) Early postlarva (430 μ length)
- (e) Early postlarva (430 μ length) showing
prodissococonch shell.
- (f) Later postlarva (500 μ length)

Note the extensions of the provincial tooth system in the dorsal margin of the postlarvae in (e) and (f). Yoshida (1936 and 1937) showed similar structures in the Mytilids Septifer virgatus and Brachidontes senhausi

- (g) Juvenile form of Modiolarca impacta. (1.5 mm length)

MYTILID HINGES

1. Mytilid 1 ? Mytilus edulis aoteanus Powell.
Left valve of late stage larva of 275 μ length.
The hinge of the right valve is almost identical.
2. Mytilid 2 ? Modiolus areolatus (Gould)
Right valve of late stage larva of 325 μ length.
Left valve of late stage larva of 325 μ length.
3. Mytilid 3 ? Perna canaliculus (Gmelin)
Right valve of late stage larva of 295 μ length.
The hinge of the left valve is almost identical.
5. Mytilid 5 ? Modiolarca impacta (Hermann)
Left valve of late stage larva of 295 μ length.
The hinge of the right valve is almost identical.

MYTILID HINGES

FIG. 11

1

2

3

5

FIG.3.12. Seasonal Variations of abundance of late stage
bivalve larvae in Bay of Islands and Wellington
Harbour. - MYTILACEA

Mytilid larvae

1. ? Mytilus edulis aoteanus Powell
2. ? Modiolus areolatus (Gould)
3. ? Perna canaliculus (Gmelin)
4. ? Xenostrobus pulex (Lamarck)
5. ? Modiolarca impacta (Hermann)

The plankton sampling area and station are given
with each abundance curve.

FIG. 12

MYTILACEA

Mytilid 1

NO. OF LARVAE PER 1000 L

Mytilid 2

Mytilid 3

Mytilid 4

FIG.12 cont.

Mytilid 5

NO. OF LARVAE PER 1000 L

FIG.3.13.MYTILACEAAdult condition index cycles for three Mytilid species.

The results are based on twentyfive animals per month.

The method of analysis of the wet and dry weight condition indices are given in the text, and in Section 3- Methods.

For further explanations, see Text.

The vertical lines give the range of values for each group of five animals.

Mean values are joined.

Relative mantle gonad thickness of Modiolarca impacta is based on the average mantle gonad thickness of the twentyfive animals. Each individual was assigned a figure out of 100 to describe the relative thickness of its mantle gonad (100 was very thick mantle gonad and 0 was no mantle gonad present). The mean for the twentyfive animals was then determined.

The monthly mean seawater temperatures are derived from Tables 1.3 and 1.9.

FIG. 13

MYTILACEA

Mytilus edulis aoteanus

Perna canaliculus

Modiolarca impacta

SUPERFAMILY PTERIACEA

Morton (1967) lists three principal families in the Pteriacea (Pteriidae, Vulsellidae and Pinnidae). Only the Pinnidae are represented in New Zealand (Powell, 1961).

- I. Adult Distribution: (refer to Tables 2.5, 2.9 and 2.10
Beu and Climo, 1971 and Wellington
Shell Club, 1969).

Powell (1961) recognized one genus with one species in the family Pinnidae, viz., Atrina pectinata zelandica (Gray). It is widespread throughout New Zealand, commonly occurring on protected sand beaches at or beyond low tide (Morton & Miller, 1968).

Atrina pectinata zelandica occurs frequently throughout Bay of Islands (Table 2.9) and Wellington Harbour (Table 2.10). It also occurs off Wellington West Coast Beaches (Wellington Shell Club, 1969).

II. Larval Features -

The larval features of the Pteriacea have received little attention in the literature. Bernard (1898) recorded three species of Pinna having triangular-shaped larvae, and Bernard (1898) and Borisjak (1909) described the hinges. The hinges consist of a series of Arcacean-like teeth (small, numerous and approximately equal in size) and posterior Mytilacean-type teeth. Ota (1961) gave a photomicrograph of the hinge of Pinna atrina japonica.

III. Common New Zealand Pteriacean larvae -

The larva of Atrina pectinata zelandica occurred in the plankton at both Bay of Islands and Wellington Harbour.

ATRINA PECTINATA ZELANDICA (Gray) Figs. 3.14 & 3.17

- A. Description - The larval shape fits the Limidae and Pinnidae groupings of Miyazaki (1962), but the larval features are Pteriaccan.

The late stage larval hinge (Fig. 3.17 left valve) has a provinculum with three-four rather poorly-developed Mytilacean-type teeth

at the posterior end, and a slightly corrugated anterior end. This is consistent with the previous larval hinge descriptions for this superfamily.

The late stage larva is large and flat, and usually reaches 350 μ in length, with a height of 350 μ and a hinge line of 125 μ length. However, the settling size seems variable, with larvae up to 450 μ in length being encountered in plankton samples.

The early umbo stages are very distinctive in shape, and these are given in Fig.3.11 c and d.

The late stage larva is triangular in shape with angular umbos of equal size. The shoulders are steep and the ventral margin is only slightly rounded. The anterior end is slightly longer and more pointed than the posterior end.

The larva is darkish in colour, and has no eyespot.

Concentric lamellae over both prodissoconch shells are clearly seen under polarised light (Fig.3.14b), but the prodissoconch 1 shell is not usually clearly delineated from the prodissoconch 2 shell.

All larval developmental stages of Atrina pectinata zelandica are very similar to those of Pinna atrina japonica given by Ota (1961) and Yoshida (1956).

B. Larval Distribution - Figs.3.18 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10 and Wellington Shell Club (1969).

This larva was encountered in the plankton at Bay of Islands, Wellington Harbour and Raumati Beach.

In Bay of Islands, it occurred occasionally at all three plankton stations. In Wellington Harbour it was frequent or common at all plankton stations. It was recorded occasionally at Raumati Beach.

C. Seasonal abundance - Figs.3.18 and 3.58.

Tables 3.3, 3.4 and 3.5.

The larva of Atrina pectinata zelandica occurred too infrequently in the plankton in Bay of Islands to record graphically. Occasional larvae were taken in plankton samples in April 1970, and February, April, May, June and October 1971. Dinamani (pers.com.) observed large numbers of larvae of this species in plankton samples from the northern side of Bay of Islands during January 1972.

In Wellington Harbour, larval peaks occurred during the mid-summer of 1971 and 1972, and during the early winter of 1971. Larval peaks also occurred in the autumn and midwinter of 1971. No larvae of this species were taken in the Wellington harbour plankton from April to November 1970.

Occasional larvae of this species were taken in the plankton off Raumati Beach in midsummer 1971.

The data suggests peak summer and winter spawnings, with only occasional trickle spawnings at other times of the year.

SUPERFAMILY PECTINACEA

The superfamily Pectinacea is represented in New Zealand by the families Dimyidae, Pectinidae and Limidae (Powell, 1961).

- I. Adult Distribution - (Refer to Tables 2.5, 2.9 and 2.10, Beu and Climo, 1971, and Wellington Shell Club, 1969).

Powell (1961) recognized one genus with one species in the Dimyidae in New Zealand (viz. Dimya maoria Powell) but the species does not occur commonly.

The Pectinidae are represented by six genera and twentythree species in New Zealand (Powell, 1961). The most abundant and widespread Pectinids are Pecten novaezelandiae Reeve, occurring subtidally on sandy muds, and Chlamys (Mimachlamys) zelandiae (Gray), also occurring subtidally, but in more open water areas.

Powell (1961) recognized four genera and eight species in the Limidae in New Zealand. Occurring subtidally, the two most common and widespread species are Limatula maoria Finlay and Divarilima sydneyensis Hedley (Morton & Miller, 1968).

Chlamys (Mimachlamys) zelandiae occurs commonly, and Pecten novaezelandiae frequently in Bay of Islands (Table 2.9), while the other Pectinids and Limatula maoria and Divarilima sydneyensis occur infrequently (Table 2.5).

Beu and Climo (1971) recorded eight Pectinids from Wellington Harbour, of which Chlamys (Mimachlamys) zelandiae occurs commonly and the rest infrequently. Limatula maoria is the only representative of the Limidae present in Wellington Harbour, and ^{it} also occurs frequently.

- II. Larval features - The larval features of the Pectinacea have received little attention in the literature. Rees (1950) gave the Pectinacean hinge features, which are identical to those of the Anomiacea, and very similar to those of the Mytilacea except that the region between the two thickened parts of the provinculum is so thin that the provincular

teeth in this region are very minute or absent.

Jorgensen (1946), Rees (1950) Sastry (1965) and Chanley and Andrews (1971) reviewed other Pectinid larval descriptions.

III. Common New Zealand Pectinacean larvae -

Only one larval species commonly encountered in the plankton samples was considered to fit this superfamily.

PECTINID 1 ? Chlamys (Mimachlamys) zelandiae (Gray)

A. Description (Figs.3.15 and 3.17)

The larval shape fits the Pectinidae grouping of Miyazaki (1962).

The hinge system is typically Pectinacean, with the provinculum of the late stage larval hinge thickened at both ends, and bearing three-four small provincular teeth (Fig.3.17, right and left valves). The region between the two ends is very reduced, and bears fine markings and no true provincular teeth. There is no lateral hinge system.

The late stage larva is relatively small, commonly being 220 μ in length and 240 μ in height, with a hinge line of 80 μ length.

The late stage larva is triangular in shape, and the umbos are equal in size, slightly knobby, and inconspicuous. The anterior end is more pointed and longer than the posterior end. The posterior shoulder is slightly more rounded than the anterior shoulder. The ventral margin is sharply rounded.

The late stage larva is dark-coloured, and at about 215 μ length it develops a marked concentric line along the outer margin of the 2nd prodissoconch shell. This can be seen in two of the larvae in Fig.3.15C. Rees (1950) recorded a similar concentric line in Pectinid B larvae.

An eyespot, 4-5 μ across, develops in larvae of about 200 μ in length.

The valves have very fine concentric lamellae which can be seen under polarised light, and there are no radial striae. The prodissoconch 1 shell is not clearly marked off except by its more punctate texture.

This larva closely resembles Pecten (= Chlamys)striatus of Jorgenson (1946) and Rees (1950).

B Larval Distribution - Figs. 3.12 and 3.58

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance tables 2.9 and 2.10

Wellington Shell Club (1969).

This larva occurred frequently or occasionally in the plankton at Bay of Islands, particularly at inner harbour stations (Confluence and Brampton Reef).

It occurred frequently in the Wellington Harbour plankton at all stations.

This larva also occurred occasionally at Raumati Beach.

The distribution and abundance of Pectinid 1 is consistent with that of the adults of the most common Pectinid, Chlamys (Mimachlamys) zelandiae.

C Seasonal abundance - Figs. 3.12 and 3.58.

This larval species occurred in the plankton in Bay of Islands during the late winter and spring of 1970, and during the autumn, winter and early spring of 1971. Larval occurrences in the plankton were low during the summer.

At Wellington Harbour, peak larval occurrences of this species in the plankton were during the spring of 1970, and during the winter, spring and early summer of 1971. The larva occurred most commonly at Raumati Beach during the midwinter.

The data from the three areas suggests that spawning of this species occurs throughout most of the year, with peaks during winter and spring, and only trickle spawnings during midsummer.

SUPERFAMILY ANOMIACEA

I. Adult distribution - (refer to Tables 2.5, 2.9 and 2.10,

Beu and Climo, 1971, and

Wellington Shell Club, 1969).

Powell (1961) recognized two genera with three species in the Anomiidae. Anomia walteri Hector is the most common species in Bay of Islands, where it occurs mainly on the basin shores (Table 2.9) Beu and Climo (1971) do not record it from Wellington Harbour.

II. Larval Features -

Jorgensen (1946) and Rees (1950), Loosanoff, Davis and Chanley (1966) and Chanley and Andrews (1971) reviewed the studies on larval Anomiidae.

The main features of late stage Anomiid larvae include

1. Inequivalve: the right shell is almost flat with a very poorly developed umbo.
2. Byssal notch, initiated in early larval life, is very distinct at or near metamorphosis.
3. The hinge structure is the same as for Pectinacea (Rees, 1950).

III. Common New Zealand Anomiid Larvae -

The larva of Anomia walteri occurred in Bay of Islands plankton samples.

ANOMIA WALTERI Hector

A. Description (Fig.3.16)

The larval shape fits the Anomiidae grouping of Miyazaki (1962), and its features are typical of this family.

The hinge system was not investigated because of the positive identification of this larva by its other features.

Late stage larvae ^{of} Anomia walteri commonly reach 250 μ in length, with a height of 250 μ , and a hinge line of 90 μ length.

In the late stage larva, the umbo of the left valve is knobby, while that of the right valve is very poorly developed.

The anterior end is slightly longer and appears more pointed because of the byssal notch on the antero-ventral margin in larvae greater than 190 μ length. The ventral margin is rounded, almost circular. The shell is colourless and fragile.

The development of the byssal notch makes earlier staged umbo larvae obvious (Fig. 3.16 a & b), and they closely resemble those of Anomia lischkei (Myazaki, 1935).

No eyespot is developed during the planktonic phase.

This late stage larva is similar to the Anomiids described by Bernard (1896), Stafford (1912), Sullivan (1948), Jorgensen (1946), Rees (1950), Loosanoff, Davis and Chanley (1966), Chanley and Andrews (1971) etc.

B. Larval distribution and seasonal abundance -

Figs. 3.18 and 3.58.

Refer to adult abundance tables 2.9 and 2.10 and

Wellington Shell Club (1969).

Anomia walteri larvae occurred in the plankton only at Bay of Islands. Spawning occurred throughout the summer, beginning in early December, when water temperatures were about 19°C. In 1970, spawning continued until April. Skerman (1959) noted more extensive times of settlement for Anomia walteri at Port of Auckland (see Table 3.1), with peaks in April-May and November-December.

SUPERFAMILY OSTREACEA

- I. Adult distribution - (Refer to Tables 2.5, 2.9 and 2.10,
Beu and Climo, 1971 and
Wellington Shell Club, 1969).

The relationships within the family Ostreidae are at present under review.

The northern rock oyster, Crassostrea glomerata (Gould) occurs abundantly, intertidally, throughout much of Bay of Islands. This species does not occur commonly south of Bay of Plenty, although it does occur occasionally in Wellington Harbour (Beu and Climo, 1971) and in Cook Strait (Morton and Miller, 1968).

At least one hypolarviparous Ostrea species occurs commonly in Bay of Islands (Dinamani, 1971) and this species is at present under study.

Ostrea lutaria Hutton is a hyperlarviparous species occurring commonly in Wellington harbour and further south.

II. Larval Features -

Chanley and Andrews (1971) reviewed the abundant literature on larval members of the Ostreidae. Rees (1950) described the larval hinge form. The photomicrographs of the larval hinge of Crassostrea angulata given recently by Pascual (1971) are excellent.

Published larval descriptions of New Zealand Ostreidae include the line drawings of the larva of Ostrea lutaria by Hollis (1963), a photomicrograph of the D-shaped larvae of Ostrea sp. from Northland (Dinamani, 1971), and a description of the larval development of Crassostrea glomerata, currently in press (Dinamani, 1973). Current work on the descriptions of New Zealand larvae of this family makes it unnecessary to elaborate further.

III. Seasonal abundance - Figs. 3.18 and 3.58.

The late stage larvae of Ostrea and Crassostrea glomerata were recorded in Bay of Islands plankton only. Both larval species occurred frequently.

Late stage larvae of Ostrea sp. occurred in Bay of Islands plankton more extensively during 1971 than 1970. In both years, peak larval densities in the plankton occurred at all stations from early summer, when the water temperatures were 18° - 19° C until late autumn, when water temperatures were again 18° - 19° C. The maximum larval density occurred in January, 1971. Trickle swarming (release of larvae from the adult) also occurred during the winter and early spring of 1971. These times of swarming and spawning are generally consistent with those given by Dinamani (1971).

Spawning in Crassostrea glomerata commenced in December, when water temperatures were about 20° C. The late stage larvae occurred frequently in the plankton samples from the Confluence and Waewaetoria stations during January and February 1971, and larvae were taken as late as mid-April in 1970, although spawning continued only to early March in 1971. These results are generally consistent with those of Rainer (1966), Greenway (1969a) and Dinamani (1971) (see Table 3.1.)

Fig.3.14. Atrina pectinata zelandica (Gray)

- (a) Late stage larva (355 μ in length).
- (b) Late stage larva showing concentric lamellae (370 μ in length).
- (c) Young larva just after D-stage (145 μ in length).
- (d) Early umbo larva (205 μ length)
- (e) Early umbo larva (330 μ in length)

Fig.3.15 PECTINID 1 ? Chlamys (Mimachlamys) zelandiae (Gray)

- (a) Early umbo larva (160 μ length)
- (b) Later umbo larva (200 μ length)
- (c) Group of eyed late stage larvae (average length 225 μ)
The two left hand larvae show the concentric line around
the outer margin of the prodissoconch 2 shell (see text).

FIG.3.16 Anomia walteri Hector

- (a) Early umbo larva (150 μ length)
- (b) Later umbo larva showing the development of the
byssal notch (190 μ length)
- (c) Late stage larva (255 μ length)

a

b

c

d

e

PECTINACEA

Pectinid 1 15

a

b

c

ANOMIACEA

Anomia walteri 16

a

b

c

FIG.3.17 Late Stage larval hinges - PTERIACEA

Upper: hinge of left valve of late stage larva at
240 μ length.

Middle: hinge of left valve of late stage larva at
290 μ length.

Lower: hinge of left valve of late stage larva at
350 μ length.

The hinge of the right valve is similar.

Late Stage larval hinges - PECTINACEA

Pectinid 1 ? Chlamys (Mimachlamys) zelandiae (Gray)

Upper: hinge of right valve of late stage larva at
225 μ length.

Lower: hinge of left valve of late stage larva at
225 μ length.

The three-four small provincular teeth at each end of the
provinculum are small and almost indiscernible.

PTERIACEAN HINGES

FIG. 17

PECTINACEAN HINGES

FIG.3.18

Seasonal variations of abundance of late stage
bivalve larvae in Bay of Islands and Wellington Harbour

PTERIACEA

PECTINACEA

ANOMIACEA

OSTREACEA

PTERIACEA

Atrina pectinata zelandica (Gray)

PECTINACEA

Pectinid 1 ? Chlamys (Mimachlamys) zelandiae (Gray)

ANOMIACEA

Anomia walteri Hector

OSTREACEA

Ostrea sp.

Crassostrea glomerata (Gould)

The plankton sampling area and station are given with
each abundance curve.

FIG. 18

PTERIACEA

Atrina pectinata zelandica

ANOMIACEA

Anomia walteri

PECTINACEA

Pectinid 1

OSTREACEA

Ostrea sp.

Crassostrea glomerata

NO. OF LARVAE PER 1000 L

SUPERFAMILY CYAMIACEA

The classification of New Zealand families within this superfamily were revised by Ponder (1971).

Ponder (1971) described the adult of Perrierina (Perrierina) taxodonta Bernard from Foveaux Strait. This species is hyperlarviparous, and larvae taken from an adult are shown in Fig.3.19. Because P. taxodonta occurs abundantly in the Foveaux Strait area, this larva may occur commonly in the plankton, but the exact length of the pelagic life is unknown.

The late stage larvae measured 275 μ in length, with a height of 225 μ , and a hinge line of 160 μ length. Their D-shaped form resembles the Pandoracean-type larvae described by Chanley and Castagna (1966) and Chanley (1969).

The late stage larvae are dark in colour, and the hinge line is slightly indented towards the centre. The shoulders are rounded and almost symmetrical. The anterior end is slightly longer than the posterior end, and the ventral margin is almost round.

SUPERFAMILY LEPTONACEA

Bivalves of this superfamily are well represented in New Zealand (Ponder, 1971) and are numerically the most abundant bivalves on the shore (Morton and Miller, 1968). Several species incubate their larvae.

Using the classification systems proposed by Moore (1969) and Ponder (1971), the following species are considered:

Superfamily Leptonacea (= Erycinacea)

Family Lasaeidae.

Kellia cycladiformis (Deshayes)

Lasaea rubra hinemoa Finlay

Lasaea maoria (Powell)

Borniola reniformis (Suter)

Family Erycinidae.

Arthritica crassiformis Powell

Arthritica bifurca (Webster)

All of these species incubate their larvae to some extent, and in the cases where larvae have been removed from the parent brood chamber, the larval identification is positive.

Using the classification of Chanley (1969), Lasaea rubra hinemoa and Lasaea maoria have direct development, Kellia cycladiformis is hyperlarviparous, and Arthritica bifurca, Arthritica crassiformis and Borniola reniformis are larviparous.

- I. Adult distribution - (refer to Tables 2.5, 2.9 and 2.10, Beu and Climo, 1971, and Wellington Shell Club, 1969).

Kellia cycladiformis occurs frequently in Bay of Islands, but is less common in Wellington Harbour. Lasaea rubra hinemoa and Lasaea maoria are widespread in New Zealand and are common in both harbours.

Borniola reniformis occurs throughout New Zealand, extending below 190 metres (100 fathoms) (Ponder, 1967) and it occurs in both harbours, frequently in Bay of Islands. Arthritica bifurca occurs abundantly in Wellington Harbour, freeliving, or commensal with Pectinaria australis (see Wear, 1966). Arthritica bifurca is abundant and freeliving in Bay of Islands (see Section 2, page 98). Arthritica crassiformis was recorded by Ponder (1965) in Wellington Harbour living commensally with Barnea similis. Arthritica crassiformis occurs frequently in Bay of Islands in this commensal relationship (see Section 2, page 105).

II. Larval Features -

Jorgensen (1946) and Rees (1950) reviewed earlier descriptions of larval leptonaceans. Rees (1950) described the larval leptonacean hinge being similar to that of the superfamily Lucinacea in that both lack a provinculum, although the straight edge of the hinge of larger larvae may appear rough or corrugated, giving the impression of feebly developed teeth.

KELLIA CYCLADIFORMIS (Deshayes)

The incubatory habit of the genus Kellia is well documented in the literature (e.g. Le Bour, 1938a, Howard, 1953, Oldfield, 1964 etc.)

A group of Kellia cycladiformis was found in a dead Mytilus shell in the low midlittoral zone at Wairoa Bay, Bay of Islands (Fig.3.3c) on 28/10/70. Individuals measured 8mm, 5mm, 3mm, 2mm, and 1 mm in length and were joined by byssal threads. There was also a group of pediveliger larvae, each with a large ciliated foot.

The largest adult contained twelve late stage larvae in the brood chamber, so making positive the identification of the larva of this species.

A. Larval description (Figs.3.20 and 3.27) -

The hinge of Kellia cycladiformis broadly agrees with the hinge system proposed by Rees (1950) for Erycinacean larvae. The late stage

larval hinge has no provinculum and no corrugations along the straight edge of the hinge. (The left valve is given in Fig.3.27). The ligament is anterior, the flanges occur on the left valve, and the ridges on the right valve. A posterior lateral tooth occurs in the right valve. There are no special teeth.

The larvae are released from the adults at 300 - 350 μ in length. Individuals encountered in the plankton were frequently up to 375 μ in length, with a height of 300 μ , and a hinge line length of 110 μ . The occurrence of a group of pediveligers around the adults in Wairoa Bay suggests that there is sometimes no planktonic phase, and development is direct (Chanley, 1969.).

The umbos of the late stage larva and pediveliger are equal in size, broadly rounded and inconspicuous. The ends are almost equal in length, and the shoulders are rounded and almost equal in size. The ventral margin is broadly rounded.

There is no pigmented eyespot.

The prodissoconch 1 shell is clearly delineated from the second prodissoconch shell, and is characterized by its punctate texture. However it lacks the radial streaks that Rees (1950) described for Erycinacean larvae. The prodissoconch 2 shell has radial striae and fine concentric lamellae, the outer two-three lamellae in the late stage larva and pediveliger being very prominent. (Figs.3.20 a - two right hand larvae).

The late stage larval shape is similar to that described for the late stage larva of the Leptonacean Montacutia ferruginosa ^{by} Jorgensen (1946), Rees (1950), Gage (1966). However this larva does not resemble that of Kellia suborbicularis described by Le Bour (1938a) & Gage (1966)

8. Larval distribution - Figs.3.12 and 3.58

Table 3.3, 3.4 and 3.5.

Refer to adult distribution tables 2.9 and 2.10 and Wellington Shell Club (1969)

The late stage larva of Kellia cycladiformis occurred frequently or commonly in Bay of Islands plankton samples, particularly at the inner harbour stations (Confluence and Brampton Reef).

It occurred occasionally, sometimes frequently, in Wellington Harbour plankton at all stations.

The larva occurred commonly in the plankton at Raumati Beach. It also occurred at the northern harbours (Table 3.5) during the spring sampling.

These occurrences are consistent with that of the adults of Kellia cycladiformis.

C. Seasonal abundance - Figs 3.28 + 3.58

The late stage planktonic larva of Kellia cycladiformis occurred in the Bay of Islands plankton samples throughout the sampling period, except for a short period during the midsummer of 1971 (February). Peak larval occurrences were during the early summer and the midwinter of 1971.

The occurrences of this larva in the Wellington Harbour plankton were generally low, but extended throughout most of the sampling period. Peak larval occurrences were in the late autumn of 1971.

The larva occurred throughout most of the year in the Raumati Beach plankton, with maximum occurrences during the winter, autumn and spring.

It appears that Kellia cycladiformis larvae swarm throughout most of the year at the three localities.

LASAEA RUBRA HINEMOA Finlay.

Lasa ea rubra hinemoa has direct larval development (Chanley, 1969), with no true planktonic phase. Oldfield (1955 and 1964) described the reproductive cycle and the veliger of Lasaea rubra (Montagu) from Plymouth, United Kingdom, and the release of the larvae as "miniature adults". Ponder (1965) mentioned the incubatory habits

and the absence of a planktonic phase in the genus Lasaea in New Zealand.

A. Description - (Figs.3.21 and 3.27)

The larva and postlarva of this species are almost identical in shape, having a D-shaped form with the anterior end slightly more pointed than the posterior end. Larvae in the brood chamber of the adult usually reach about 550 μ in length, with a height of about 375 μ . However, these are technically postlarvae, since the hinge has adult elements (Fig.3.27). Late stage larvae are considered to reach 410 μ in length, with a height of about 285 μ .

The larval shell is colourless and transparent during incubation, and has widely separated concentric lamellae which are visible under polarised light. The ventral margin is rounded, and the shoulders lie on the hinge line. The shell thickens and develops a reddish-brown tinge prior to release, and the concentric lamellae become more marked (Fig.3.21c).

B. Swarming Cycle - Fig.3.29

Fig.3.29A gives the percentage of forty adults bearing larvae and postlarvae over 320 μ in length at Wairoa Bay, Bay of Islands (Fig.3.3c) during the period February 1971 to May 1972. More than 5% of the adults throughout the year carried larvae or postlarvae, with the maximum number of adults carrying larvae or postlarvae in the winter of 1971 (May to August) and possibly in the winter of 1972 (May to ?). Minimum numbers of adults carried larvae or postlarvae during the mid-spring of 1972. This was just after the main release (swarming) period, which occurred at water temperatures of 16° - 17°C. A smaller swarming appears to have occurred during the late summer of both years. This data therefore suggests spring and late summer spawnings and swarmings.

The larvae or postlarvae in any one individual adult were all at the same stage of development. Fig.3.29B shows that at any one time there was a considerable range in the size of larvae or postlarvae carried by different adults. This suggests that some swarming is occurring most of the year. Oldfield (1964) reported developing embryos in adult Lasaea rubra at Plymouth from May to November (summer to autumn) with a few during the spring, indicating a more defined spawning season than that which occurs in New Zealand.

The maximum number of larvae which were observed in any single adult was thirty-three. These were 500 μ in length, and occurred in an adult 2.08mm in length. The smallest adult carrying larvae was 1mm in length, and it carried two larvae at 400 μ length. The largest postlarva encountered in the brood chamber of an adult was 580 μ in length, but most postlarvae are released at approximately 560 μ length (cf. 600 μ length - Oldfield, 1964).

The larvae of Lasaea rubra hinemoa were very seldom encountered in the plankton because of the virtual absence of a pelagic period. This direct development ensures a less hazardous larval life, but it minimises the dispersal factor. Lasaea rubra hinemoa is the culmination of the evolutionary trend towards the protection of larvae by the adults proposed by Chanley (1969).

LASAEA MAORIA (Powell)

A. Description - (Fig.3.22)

The larva and postlarva are very similar to those of Lasaea rubra hinemoa, except that they are slightly deeper and less angular, and are white in colour.

Lasaea maoria probably has a similar life history to Lasaea rubra hinemoa, with the larvae very seldom being taken in the plankton.

Of six adult Lasaea maoria collected at Eastbourne, Wellington harbour (Fig.1.16) on 21/1/72, two contained larvae at 400 - 450 μ length. Of fifteen collected at the same place on 30/3/72, two

contained larvae at 300 μ length.

BORNIOLA RENIFORMIS (Suter) - (Fig.3.23.)

An adult Borniola reniformis collected at Wairoa Bay (Fig.3.3C) on 12/2/71 contained numerous D-shaped larvae at 120 μ length. A group of the larvae are shown in Fig.3.23. Of twentyfive adults opened during the rest of 1971, none contained larvae.

ARTHITICA CRASSIFORMIS Powell. (Fig.3.24).

D-shaped larvae of Arthritica crassiformis at 110 μ length are given in Fig.3.24. They were taken from adults which were living commensally with Barnea similis at Te Puna, Bay of Islands (Fig.3.3C) on 17/5/72.

Of forty adult Arthritica crassiformis opened in midsummer (12/1/72), and forty in winter (17/5/72), 10% each time contained numerous larvae of maximum length 150 μ , and average length 125 μ . Since the larvae contained in the brood chamber were always numerous (many hundreds) and the adults are small (up to about 4 mm. length), most of the larval development must occur during a pelagic phase.

ARTHITICA BIFURCA (Webster)

Wear (1966) observed the larvae of Arthritica bifurca being incubated to at least the "shelled prodissoconch" stage. The largest incubated larvae observed in the present study were D-shaped and 140 μ in length, although the most common length was about 120 μ . (D-shaped larvae of 120 μ length are shown in Fig.3.25d).

Adult Arthritica bifurca of 2-3 mm. length were collected approximately monthly from Petone Beach from October 1971 to July 1972. Twenty-five to thirty per cent of the adults were carrying larvae every month, and larvae in any one adult were always at the same stage of development.

The small size of the larvae being carried, their high numbers (many hundreds), and the small size of the parent (usually 2-3 mm. length) suggests that the larvae are released early in development, probably at about 120 - 140 μ in length. Wear (1966) suggested the larvae had a short pelagic period.

A. Description of late stage larva -(Fig.3.25 b and c, and 3.27.)

The identification of the late stage planktonic larva of Arthritica bifurca requires verification. The provisionally identified late stage larval form is given in Fig.3.25b, and an early dissoconch of Arthritica bifurca (confirmed by Dr.F.M.Climo, Dominion Museum) appears to exhibit this prodissoconch 2 shell shape. (Fig.3.25 d).

The shape of the provisional Arthritica bifurca late stage larva fits the Becheftia larva.

by Gage for Myrella bidentata is very similar to that observed for this provisional Arthritica bifurca larva.

B. Larval distribution - Figs.3.28 and 3.58

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.20 and Wellington Shell Club (1969).

This larva occurred commonly or abundantly in Bay of Islands plankton samples from all stations, particularly the inner harbour stations (Confluence and Brampton Reef).

In Wellington Harbour this larva occurred commonly or abundantly at all four plankton stations.

It also occurred, often commonly, in Raumati Beach plankton samples, and in the spring plankton samples from the northern harbours (Table 3.5).

The larval occurrences are consistent with that of the adults, which occur commonly or abundantly at all these localities.

C. Seasonal occurrence - Figs.3.28 and 3.58.

Tables 3.3, 3.4 and 3.5.

This larva occurred in the Bay of Islands plankton throughout most of the sampling period, and, except for a short period during the spring, it was one of the dominant species in the harbour (Fig.3.58). Peaks in larval abundance occurred during the winters of 1970 and 1971, and during the early summer of 1970-71,

In Wellington Harbour, this larva occurred in the plankton frequently throughout most of the sampling period, but it occurred commonly or abundantly during the midsummer and autumn of 1971. It was one of the dominant bivalve larvae in Wellington harbour during the autumn of 1971 (Fig.3.58).

At Raumati Beach this larva occurred in the plankton mainly during the autumn of 1972.

It occurred in spring and summer plankton of Raglan, Kaipara

and Ohiwa harbours and at Mahurangi.

LEPTONACEAN 1

Possibly Borniola reniformis (Suter)

A late stage larva occurred frequently or commonly in Bay of Islands and Wellington Harbour which had several Leptonacean larval characteristics, but whose provisional identity was uncertain.

A. Description - (Figs.3.26 and 3.27).

The larval shape most closely fits the Rochefortia grouping of Sullivan (1948) and the late stage larva resembles that of Rochefortia planulata given by Sullivan (1948).

The late stage larval hinge appears to be typically Leptonacean and is given in Fig.3.27 (right and left valves). There is no provinculum, and the straight edge of the hinge is almost smooth. The ligament is anterior (not visible in the photomicrograph), and the flanges are on the left valve. The lateral teeth are not well developed, and there are no special teeth.

The late stage planktonic larva is large, usually reaching 425 μ in total length, with a height of about 350 μ , and a hinge line of 110 μ length.

The umbos of the late stage larva are knobby and equal in size. The anterior end is slightly longer and less pointed than the posterior end, and the anterior shoulder is more rounded than the posterior shoulder. The ventral margin is broadly rounded.

The larva is of darkish colour, and has no pigmented eyespot.

Under polarised light, concentric lamellae are seen over both prodissoconch shells, and radial striae occur, particularly over the 2nd prodissoconch shell (Fig.3.26 b).

B. Larval distribution - Figs.3.28 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10 and Wellington Shell Club (1969).

This late stage larva occurred frequently in Bay of Islands plankton samples, particularly at the inner harbour stations (Confluence and Brampton Reef).

It often occurred commonly in Wellington Harbour at all four plankton stations.

This larva was not recorded in the plankton from Raumati Beach, but it did occur occasionally in Kaipara Harbour, during the spring sampling.

These larval occurrences are consistent with that of the adults of Borniola reniformis (Suter), whose D-shaped larva was described in Fig.3.23.

C. Seasonal abundance - Figs.3.28 and 3.58.

This larva occurred in Bay of Islands plankton samples throughout the sampling period, but mainly during the autumn of 1970, the summer of 1970-71 and the spring of 1971.

In Wellington harbour plankton, larval peaks were during the summer and late autumn and winter, with low larval densities during the spring.

FIG.3.19

Perrierina (Perrierina) taxodonta Bernard

Late stage larvae (270 μ in length) taken from the adult brood chamber.

FIG.3.20

Kellia cycladiformis (Deshayes)

(a) group of late stage larvae (average length 375 μ)

Note the concentric lamellae at the outer edge of the 2nd prodissoconch shell in the two right hand larvae.

(b) young adult showing the prodissoconch 2 shell shape.

FIG.3.21

Lasaea rubra hinemoa Finlay

(a) postlarva at 530 μ length prior to release. from parent

(b) group of larvae (average length 400 μ)

(c) single valves of postlarva at 530 μ length showing concentric lamellae.

FIG.3.22

Lasea maoria (Powell)

(a) pair of postlarvae at 550 μ length prior to release from parent.

CYAMIACEA

Perrierina taxodonta FIG. 19

LEPTONACEA

Kellia cycladiformis 20

Lasaea rubra hin. 21

Lasaea maoria 22

FIG.3.23

Borniola reniformis (Suter)

D-shaped larvae (average length 120 μ)

FIG.3.24

Arthritica crassiformis Powell

D-shaped larvae (average length 110 μ)

FIG.3.25

Arthritica bifurca (Webster)

(a) group of D-shaped larvae (average length 120 μ)

(b) group of the provisional late stage larva of

Arthritica bifurca (300 μ length).

(c) single valve of late stage larva showing concentric lamellae.

(d) dissoconch shell of Arthritica bifurca showing larval prodissoconch 2 shell shape.

FIG.3.26

Leptonacean 1 (possibly the late stage larva of

Borniola reniformis (Suter)

(a) group of late stage larvae (average length 400 μ)

(b) two single valves showing concentric lamellae and radial striae. (length 375 μ).

Borniola reniformis FIG. 23

Arthritica crassiformis 24

Arthritica bifurca 25

? Leptonacean I 26

Kellia cycladiformis (Desbayes)

Left valve of late stage larva at 375 μ length.

Lasaea rubra hinemoa Finlay

Upper: hinge of left valve of postlarva at 535 μ length.

Lower: hinge of right valve of postlarva at 535 μ length.

? Arthritica bifurca (Webster)

Upper: right valve of late stage larva at 300 μ length.

l = ligament

lt = laminar tooth.

Lower: left valve of late stage larva at 300 μ length.

? Leptonacean 1 (possibly late stage larvae of

Borniola reniformis (Suter).

Upper: hinge of right valve of late stage larva at
400 μ length.

p = provinculum.

Lower: hinge of left valve of late stage larva at
400 μ length.

Lasaea rubra

Arthritica bifurca (?)

LEPTONACEAN HINGES

Con t.

? Leptonacean 1

FIG. 27 con t

FIG.3.28

Seasonal variations of abundance of late stage larvae
in Bay of Islands and Wellington harbour - LEPTONACEA

Kellia cycladiformis (Deshayes)

? Arthritica bifurca (Webster)

Leptonacean 1 (possibly Borniola reniformis (Suter))

The plankton sampling area and station are given
with each abundance curve.

FIG. 28

LEPTONACEA

Kellia cycladiformis

? *Leptonacean 1*

NO. OF LARVAE PER 1000 L

Arthritica bifurca (?)

FIG.3.29

Lasaea rubra hinemoa from Wairoa Bay, Bay of Islands.

A. Percentage of forty adults carrying larvae.

Monthly mean water temperature for Bay of Islands
(see Table 1.3).

B. The size of the larvae carried by the adults each
sampling date.

FIG 29 *Lasaea rubra hinemoa* Finlay from Bay of Islands

SUPERFAMILY VENERACEA

Morton (1967) listed two main families in this superfamily, the Veneridae and the Petricolidae. Powell (1961) recognized no genera in the family Petricolidae in New Zealand, but recognized twelve genera with twentytwo species in the family Veneridae, many of which occur throughout the country.

I. Adult distribution: (refer to Tables 2.5, 2.9 and 2.10

Beu and Climo, 1971 and

Wellington Shell Club, 1969).

Dosinia lambata (Gould) is widespread throughout New Zealand in waters 4 - 21 metres deep (Morton and Miller, 1968). Dosinia anus (Philippi) is a typical open coast species, Dosinia subrosea (Gray) occurs on protected harbour flats, and Tawera spissa (Deshayes) is abundant in many areas, often in coarse shell gravel (Morton and Miller, 1968). Chione stutchburyi (Gray) is one of the most numerous bivalves on sheltered shores. Venerupis largillierti (Philippi) is common in silty sand on enclosed beaches, particularly on Zostera flats (Morton and Miller, 1968).

II. Larval characteristics:

Jorgensen (1946), Rees (1950), La Barbera and Chanley (1970) and Chanley and Andrews (1971) reviewed the larval characteristics and the published descriptions of Venerid larvae. Most pelagic Venerid larval species are small and have few characteristics in common, except that they develop a broadly rounded umbo, and none have a hinge line less than 55 μ in length (La Barbera and Chanley, 1970). Rees (1950) gave two main larval hinge forms, and also emphasised the prominent concentric lines (lamellae) and the distinct lateral ridges in the larval shells. Other observations on Venerid larval hinges have included those of Quayle (1952), Ansell (1962) and Chanley and Andrews (1971), all of which in general agree with Rees's descriptions.

III. Common New Zealand Venerid larvae:

Venerid late stage larvae are often small and indistinctive, making them a difficult group to recognize. Often the hinge elements are indistinctive, and difficult to photograph.

Five larval species observed in the plankton samples have been placed in the Veneridae on their hinges and larval features.

VENERID 1. ? Chione stutchburyi (Gray)

A. Description (Figs.3.30 and 3.34).

The larval shape most closely fits the Mulinia grouping of Sullivan (1948) and has most similarities to the Venerid (Venerupsis semidecussata) group of Miyazaki (1962).

The late stage larval hinge (Fig.3.34 right and left valves) is consistent with the Veneracea Type A hinge of Rees (1950) and has very small provincular teeth. The solid lateral tooth at the anterior end of the right valve is not prominent, and it does not show in Fig.3.34. The ligament is posterior. The flanges are on the left valve and the ridges on the right valve, but they do not show clearly in the photograph.

The hinge is not Mactracean Type A of Rees (1950) since no teeth are particularly enlarged, nor do larvae greater than 250 μ in length have a spatulate tooth. Furthermore, this larva bears the widely separated, prominent concentric lamellae which are characteristic of the Veneridae. These can be seen even under normal light conditions. (Fig.3.30b), and they obscure the division between the two prodissoconch shells. There are no radial striae. Prominent lateral ridges extend well down the anterior and posterior margins of the larva, as Rees (1950) found for other Venerid larvae.

The late stage larva usually reaches 240 μ in length, with a height of 230 μ and a hinge line length of 80 μ .

The umbos of the late stage larva are equal in size and angular. The anterior end is slightly longer and more pointed than the posterior end, and both shoulders are straight and quite steep. The ventral margin is rounded. The larva is darkish in colour, and no pigmented eyespot is developed.

Dissoconch shells of Chione stutchburyi collected from Petone Beach in Wellington Harbour (Fig.3.38) and off postlarval plate collections in the harbour, are shown in Figs.3.38 C and D. The outline of the

prodissoconch 2 shell can be seen in Fig.3.30c. The concentric lamellae remain prominent throughout postlarval development.

This larva resembles the Venerupis pullastra larva of Quayle (1952) and Venera G of Rees (1950), but has little similarity to Chione cancellata of La Barbara and Chanley (1970).

B. Larval distribution. - Figs.3.35 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10 and Wellington Shell Club (1969).

This larva occurred commonly, sometimes abundantly, at all three Bay of Islands plankton sampling stations.

In Wellington Harbour it occurred frequently, sometimes commonly at all four plankton sampling stations.

The larva did not occur in the plankton at either Raumati Beach or Dargaville Beach, the two west coast sampling areas.

The larve occurred at the four northern harbours (Table 3.5) during the spring plankton sampling.

The distribution and abundance of this larva therefore relates well with the distribution and abundance of the adults of Chione stutchburyi. The larvae at the more open water Waewaetoria station in Bay of Islands probably originate from muddy bays along the southern shore of the harbour (see Fig.1.4).

C. Seasonal occurrence - Figs.3.35 and 3.58.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands this larva occurred throughout the sampling period, with very marked peak larval occurrences in the spring of both years. At these times, this larva was one of the dominant species occurring in the plankton. (Fig.3.58)

The monthly dry weight II condition index cycle (see Section 3, Methods) for adult Chione stutchburyi from Wairoa Bay, Bay of Islands (Fig.3.3C)

during 1970-71 is given in Fig.3.36. The condition index curve roughly follows the monthly mean water temperature, with peaks in water temperature and condition in early February 1971. However, a rapid decline in condition, which may have been due to spawning, occurred late in February and during March. A small increase in the number of larvae in the plankton, particularly at the inner harbour stations (Confluence and Brampton Reef), occurred at this time. The condition of Chione stutchburyi adults then rapidly improved until in late April it was almost as high as it had been in the previous February. A slow decline of condition then occurred until August 1971, followed by a more marked decline between August and October. This was consistent with the peak spring larval occurrences in September and October 1971. The condition of the adults then improved as the water temperature increased.

A microscopical examination of the gonads of adult Chione stutchburyi from Wairoa Bay was made on several occasions during 1970-71. The gelatine embedding technique described on page 144 was used. On 28/8/70, when the condition index was very low, 60% of the twentyfive Chione stutchburyi studied were in an "indeterminate" gonad state, and 40% were completely evacuated. (Gonad categories 2 and 1). However, on 12/2/71, when the condition index was higher, all of the twentyfive individuals contained ripe eggs or sperm (gonad category 4), (60% were females). Fifty per cent of twentyfive animals opened on 26/6/71, when the condition index was falling, had ripe eggs or sperm, while 30% had an indeterminate gonad state, and 20% were evacuated. This was consistent with part of the adult stock having spawned. Finally, on 24/10/71, when the condition index was the lowest, 96% of the twentyfive individuals opened had indeterminate gonads, and only 4% had ripe sperm.

These few examples suggest good correlations between the condition index cycle, and the gonad cycle for adult Chione stutchburyi, although gonads were not microscopically examined during the drop in condition index in late February and March, 1971. The larval density in the

plankton was also in general agreement with the gonad and condition cycles.

In Wellington Harbour this larva occurred in the plankton throughout much of the sampling period, with peak larval densities during the summer of 1970-71, spring 1970 (which was not repeated in spring, 1971) and the winter of 1971. Lowest larval densities occurred in the late spring and early summer of 1970, late summer 1971 and spring 1971.

The monthly dry weight II condition index for Chione stutchburyi from Petone Beach in Wellington Harbour (Fig.3.38) for 1970-71 is given in Fig.3.36. The agreement between the condition index cycle of the adults and the monthly mean water temperature is less than it was in Bay of Islands, but it is still evident. The main declines in the condition index occurred during September - October, 1970, December - January 1970-71, and December - January 1971 - 72.

There was also a steady decline in condition during much of the late summer, autumn and winter of 1971, which may have obscured more rapid drops in condition due to spawning. The condition index cycle is consistent with the spring 1970, summer 1970-71, and summer 1971-72 larval peaks in the plankton. The winter 1971 larval peak is not inconsistent with the steady decline in condition of the adults during that time.

Microscopical examination of the gonads of adult Chione stutchburyi (embedded using the gelatine technique) from Petone Beach were made on several occasions during 1970-72. On 15/11/70 all the gonads were of category 4, containing ripe eggs or sperm (75% were females). On 10/12/70, 50% contained ripe eggs or sperm (gonad category 4), while 50% were evacuated or indeterminate (gonad category 1 and 2 respectively), indicating that the summer spawning had already commenced. The summer spawning was largely over by 23/2/71, when 40% contained ripe eggs and sperm (gonad category 4), 40% had developing eggs or sperm (gonad category 3) and 20% were evacuated or indeterminate (gonad categories 1 and 2). Spawning had recommenced by mid-April 1971, when 32% contained ripe eggs and sperm (gonad category 4), 20% developing gametes (gonad category 3) and 48% were evacuated or indeterminate (gonad categories 1 and 2.). The proportions were roughly the same

in early July 1971, but by the beginning of September 1971 there was little spawning occurring, with 92% of the animals containing ripe eggs or sperm.

Spawning had commenced by the beginning of December 1971, with 32% containing ripe eggs and sperm, 20% with developing gametes, and 48% were evacuated or indeterminate.

Again, the condition index cycle, the microscopical gonad examinations, of the adult stock, and the abundance of the larvae in the plankton, were in general agreement.

The condition index of adult Chione stutchburyi from Wairoa Bay, Bay of Islands, showed considerably more variation, and averaged about 15% less than that of Chione stutchburyi at Petone Beach, Wellington Harbour. Presumably, the Petone Beach population had a better food supply than the more topographically enclosed Wairoa Bay could provide.

There was also a steady overall decline in the condition index cycle of Chione stutchburyi at Petone Beach, Wellington Harbour, over the two years of observations. The December - January 1970-71 condition index was about 65%, while that for December 1971 was about 55%. The decline may be in part due to the termination of the release of organic waste materials from the Gear Meat Works into the water in this area in December 1970. A very large population of Chione stutchburyi had become established in the region of the outlet, and the condition index may now be steadily declining because of there being less food available.

VENERID 2.

? Dosinia lambata

A. Description. (Figs.3.31 and 3.34)

The larva does not fit any of the groupings of Sullivan (1948) or Miyazaki (1961). However, the hinge (Fig.3.34 left valve) resembles that of Venerid 1, and has a Type α provinculum (Rees, 1950) with many small provincular teeth. The solid lateral tooth at the anterior end of the right valve is small. The ligament is posterior, and the flanges are on the left valve and ridges on the right valve. The lateral ridges are

much less prominent than in Venerid 1.

Distinct concentric lamellae, typical of Venerid larvae, are visible under ordinary light on the outer margin of the 2nd prodissocoench shell, are these can be seen in Fig.3.31b. Under polarised light, the prodissocoench 1 shell is quite clearly delineated from the prodissocoench 2 shell, and is generally more punctate in texture. There are no radial striae.

The late stage larva often reaches 260 μ in length, with a height of 225 μ and a hinge line length of 90 μ .

The umbos are equal in size and angular, although less angular than in Venerid 1. The anterior end is more pointed and longer than the posterior end, and the ventral margin is broadly rounded. The posterior shoulder is steeper and shorter than the anterior shoulder.

There is no pigmented eyespot.

This larva most closely resembles the largest larva of Venerid A pictured by Rees (1950).

B. Larval Distribution Figs.3.35 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10, and Wellington Shell Club (1969).

This larva occurred much more abundantly in Wellington Harbour than in Bay of Islands. In Wellington Harbour it occurred commonly, sometimes abundantly, at all four plankton stations during the sampling period, while in Bay of Islands it occurred most abundantly at the two inner harbour stations (Confluence and Brampton Bay).

The larva did not occur at either Raumati or Dargaville Beaches, nor during the spring sampling at the four northern harbours (Table 3.5). The occurrence of this larva is most consistent with the occurrence of the adults of Dosinia lambata. Although Dosinia lambata does occur on Wellington West Coast beaches (Wellington Shell Club, 1969), its valves are not commonly found cast up on Raumati Beach.

Another Venerid, Dosinia greyi, occurs commonly in Wellington Harbour, but this species is not as abundant in the harbour as Dosinia lambata (see Table 2.6), and it occurs rarely in Bay of Islands.

C. Seasonal occurrence - Figs.3.35 and 3.58.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands, this larva occurred most abundantly in the plankton during the midsummer of 1971 and the springs of 1970 and 71. There were also small occurrences during the winters of both years.

In Wellington Harbour, peak occurrences in the plankton were during the early summers of both years, and the winter of 1971.

The occurrence of the larvae in the two areas suggests peak summer spawnings, and possibly winter and/or spring spawnings.

VENERID 3. ? Tawera spissa (Deshayes)

A. Description - Figs.3.32 and 3.34

The larval shape most closely fits the Mulinia grouping of Sullivan (1948).

The late stage larval hinge does not precisely fit any described by Rees (1950), but it has closest affinities to the Veneracean Type C hinge. Fig.3.34 gives the left and right valves. The ligament is approximately central, a feature typical of the Tellinacean hinge of Rees (1950). However, the provincular teeth are of Type c and there is a solid lateral tooth at the anterior end of the right valve (see Fig. 3.34) which is large, but not spatulate as it is in the Mactracea. It is opposed by a long projection at the anterior end of the left valve. The lateral ridges are not as marked as Rees (1950) noted for other Veneracean larvae, but the prominent, quite widely separated concentric lamellae, particularly over the prodissocench 2 shell (see Fig.3.32), are typically Veneracean. Under polarised light, no radial striae are visible, and the first prodissocench

shell is not clearly delineated from the second.

The late stage larva is small, usually reaching 250 μ in length, with a height of 225 μ and a hinge line of 75 μ length.

The umbos are equal in size, slightly angular but inconspicuous. The anterior end is longer and more pointed than the posterior end, and the anterior shoulder is longer and less steep than the posterior shoulder. The ventral margin is broadly rounded.

This larva does not closely resemble any published bivalve larva I have encountered in the literature.

B. Larval distribution - Figs.3.35 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10, and Wellington Shell Club (1969)

This larva occurred frequently in the Bay of Islands plankton samples, and was taken at all three plankton stations.

It occurred less frequently in the Wellington Harbour plankton samples, but in similar densities at all four of the plankton stations.

It did not occur at either Raumati Beach or Dargaville Beach on the west coast, and it was not observed in the spring plankton samples from the four northern harbours. (Table 3.5.)

Adults of Tawera spissa occur abundantly in Bay of Islands, and frequently in Wellington Harbour. Although the species does occur on the Wellington west coast beaches (Wellington Shell Club, 1969), the small numbers of empty valves cast up along Raumati Beach suggests it is not as abundant in this area as it is in Bay of Islands and Wellington Harbour.

The distribution of the larvae in the plankton is therefore generally consistent with that of the adults of Tawera spissa.

C. Seasonal occurrence - Figs.3.35 and 3.58

Tables 3.3, 3.4 and 3.5.

In Bay of Islands this larva occurred in the plankton mainly during the summer and autumn of 1971, although trickle spawnings did occur at other

times of the year.

The occasional microscopical examination of the gonads of adult Tawera spissa from Waireka, Bay of Islands (Fig.3.3C) during 1971 showed general agreement with the occurrence of Venerid 3 larvae in the Bay of Islands plankton. Spawning was under way by 4/12/71, when 75% of the animals had ripe eggs or sperm (gonad category 4), while 25% were evacuated or indeterminate (gonad categories 1 and 2 respectively). By 20/3/71 all the animals studied had evacuated or indeterminate gonads. By 28/4/71 spawning was complete, with 92% of the individuals having developed mature sperm or eggs, and the remainder having indeterminate developing gonads. On 30/6/71 and 2/9/71 the proportions of mature and evacuated or indeterminate gonads remained at 92% and 8% respectively.

In Wellington Harbour peak occurrences of Venerid 3 larvae in the plankton were during the early winters and summers of both years, with trickle spawning at other times.

In summary, this species occurs in the plankton of both harbours in greatest densities during the summer and early winter.

VENERID 4. No provisional identification was made.

A. Description. Figs.3.33 and 3.34.

The larval shape does not satisfactorily fit any groupings of either Sullivan (1948) or Miyazaki (1961).

The late stage larval hinge (Fig.3.34 right and left valves) is most similar to Veneracean Type A of Rees (1950). The ligament is posterior (not seen in the photomicrograph), and the provinculum is Type a. A group of two-three enlarged provincular teeth occur near the posterior end of the right valve (see Fig.3.34). Rees (1950) suggests that this is a Macracean feature, although it is usually the first or second tooth from the end which is enlarged.

The prominent concentric lamellae (see Fig.3.33) which can be

seen in both predisseccench shells under polarised or ordinary light, and the very distinct lateralridges, with large anterior and posterior extensions in the right valve, are typical Veneracean features. The solid lateral tooth at the anterior end of the right valve is small, and does not show clearly in Fig.3.33

The late stage larva is relatively small, usually reaching about 250 μ in length, with a height of 210 μ and a hinge line length of 90 μ .

The umbos are equal in size and ⁱⁿ⁻conspicuously knobby. The anterior end is more pointed and longer than the posterior end, and the posterior shoulder is steeper and shorter than the anterior shoulder. The ventral margin is broadly rounded, almost flat.

This larva does not resemble any published descriptions I have seen.

B. Larval distribution - Figs.3.35 and 3.58

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10 and Wellington Shell Club (1969).

This larva occurred very infrequently in the Wellington Harbour plankton, but commonly in the Bay of Islands plankton. It was not recorded at the west coast stations (Raumati and Dargaville Beaches), but did occur at Mahurangi in January 1972.

C. Seasonal occurrence - Figs.3.35.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands this larva occurred in the plankton mainly during the spring of both years. There was a smaller spawning during the autumn of 1971, and there was also evidence of an autumn spawning in 1970.

The Wellington Harbour larval occurrences, although very low, were in late spring 1971,

In general this species appears to spawn mainly during the spring and autumn.

FIGURES

3.30, 3.31, 3.32 and 3.33

FIG.3.30

VENERID 1

? Chione dutchburyi (Gray)

- (a) group of late stage larvae (average length 240 μ)
- (b) group of late stage larvae - single valves, showing concentric lamellae.
- (c) early postlarva (dissocoench,) 490 μ length.
- (d) juvenile shell, 900 μ length.

FIG.3.31

VENERID 2

? Dosinia lambata (Gould)

- (a) group of late stage larvae (average length 250 μ)
- (b) late stage larva (250 μ length) showing prominent concentric rings in the outer prodissocoench 2 shell.
- (c) single valves of late stage larva (250 μ length)

FIG.3.32

VENERID 3

? Tawera spissa (Deshayes)

- (a) single valves of late stage larva (250 μ length).

Note the prominent concentric lamellae.

FIG.3.33

VENERID 4

- (a) group of late stage larvae (average length 250 μ)
- (b) single valves of late stage larva (255 μ in length).

Note the prominent concentric lamellae and lateral ridges.

Venerid 1 FIG. 30

Venerid 2 31

Venerid 3 32

Venerid 4 33

VENERID HINGES

1. Venerid 1. ? Chione stutchburyi (Gray)

Upper: right valve of late stage larva of 245 μ length.

Lower: left valve of late stage larva of 245 μ length.

2. Venerid 2. ? Dosinia lambata (Gould)

Right valve of late stage larva of 250 μ length).

3. Venerid 3. ? Tawera spissa (Deshayes)

Upper: right valve of late stage larva of 250 μ length.

l = ligament

lt = lateral tooth.

Lower: left valve of late stage larva of 250 μ length.

p = projection opposing lateral tooth.

4. Venerid 4

Upper: right valve of late stage larva of 255 μ length.

t = group of two-three enlarged provincular teeth at
the posterior end of the provinculum.

r = ridge.

Lower: left valve of late stage larvae of 255 μ length.

f = flange.

VENERACEAN HINGES

FIG. 34

Venerid 1

2

3

VENERACEAN HINGES—
cont

FIG.34 cont

Venerid 4

FIG.3.35

Seasonal variations of abundance of late stage bivalve larvae
in Bay of Islands and Wellington Harbour - VENERACEA

Venerid 1 ? Chione stutchburyi (Gray)

Venerid 2 ? Dosinia lambata (Gould)

Venerid 3 ? Tawera spissa (Deshayes)

Venerid 4 ?

The plankton sampling area and station are given with
each curve.

FIG. 35

VENERACEA

Venerid 1

Venerid 2

NO. OF LARVAE PER 1000 L

FIG. 35 cont

VENERACEA cont

Venerid 3

Venerid 4

The dryweight II condition index cycles for twentyfive animals per month from Wairoa Bay, Bay of Islands, and Petone Beach, Wellington Harbour (Fig.3.3.)

The vertical lines give the range in the condition index values of the five groups of five individuals analysed. Mean values are joined.

For explanation, see Text, and Section 3, Methods.

The monthly mean seawater temperatures for Bay of Islands are from Table 1.3 and those for Wellington Harbour from Table 1.9.

BAY OF ISLANDS

WELLINGTON

FIG. 36

SUPERFAMILY MACTRACEA

Powell (1961) recorded the Mactracean families Mactridae and Amphidesmatidae in New Zealand, but the Amphidesmatidae members are now being assigned to the Mesodesmatidae (Beu, 1971)

- I. Adult distribution - (refer to Tables 2.5, 2.9 and 2.10, Beu and Climo, 1971, and Wellington Shell Club, 1969).

- (a) The Mactridae are typically bivalves of the open coast, (Morton and Miller, 1968) and Powell (1961) recorded eight genera with nine species occurring in New Zealand. The most common Mactrids include:

Mactra discors Gray, which is the most common Mactrid, occurring mainly on west coast sand beaches. It is not recorded in Bay of Islands, probably because of the protected nature of the harbour, but Beu and Climo (1971) do record it in Wellington Harbour, where it occurs uncommonly.

Cyclomatra ovata (Gray) is the only Mactrid occurring commonly in enclosed harbours and estuaries (Morton and Miller, 1968), but this species is also occasionally recorded on west coast beaches.

Scalpomactra scalpellum (Reeve) occurs frequently in the basin area of Bay of Islands, and much less frequently in Wellington Harbour, and it also occurs on the west coast beaches.

Spisula aequilateralis (Deshayes) occurs commonly on west coast beaches, but it is unrecorded in Bay of Islands, and is scarce in Wellington Harbour.

Zenatia acinaces (Quoy and Gaimard) occurs frequently in Wellington Harbour, and it also occurs in the basin area of Bay of Islands, and on the west coast beaches.

In summary, the family Mactridae is better represented on open beach areas, particularly on the west coast, than in either Bay of Islands or Wellington Harbour.

- (b) The Mesodesmatidae are represented in New Zealand by ^{one} genus with three common species.

Paphies australe (Gmelin) is often a dominant bivalve on protected sand-beaches and lower estuaries throughout New Zealand. It is abundant in Bay of Islands, and common in Wellington Harbour, but rare on the west coast.

Paphies subtriangulatum (Wood) is typically an open shore bivalve occurring throughout New Zealand, but it is replaced in some areas by Paphies ventricosum (Gray). Paphies ^{sub-}triangulatum occurs frequently in outer Bay of Islands beaches, but it is uncommon in Wellington Harbour. It occurs abundantly on the west coast beaches.

II. Larval characteristics -

Jorgensen (1946), Rees (1950), Chanley (1965b) and Chanley and Andrews (1971) reviewed some larval Mactrid descriptions. However, there have been no comprehensive accounts of Mactracean larval characteristics, and Chanley (1965b) noted that there is no common taxonomic feature by which the group can be recognized.

Jorgensen (1946) and Rees (1950) described the Mactrid hinge structure, which may take one of at least two forms. The first has a Type a provinculum, and often there is a large, characteristic, spatulate tooth, while the second has a Type c provinculum. Rees (1950) found the first type to be the most common among the North Sea Mactrids.

III. Common New Zealand Mactracean larvae -

Three commonly occurring planktonic bivalve larvae have been placed in the Mactracea by their hinges. Classification to family level and beyond has been made mainly by relating the presence of larvae to the presence of adult species in the area.

MACTRACEAN 1

? Paphies australe (Gmelin)

A. Description - Figs. 3.37 and 3.40

The larval shape most closely fits the Mulinia grouping of Sullivan (1948) and resembles the Mactrid (Mactra sulcata) grouping of Miyazaki (1962)

The late stage larval hinge (Figs.3.40 right and left valves) is Mactracean Type A of Rees (1950). It has a Type a provinculum, and a large, well-developed spatulate tooth in the right valve. (Rees, 1950, however, recorded the spatulate tooth on the left valve in Mactracean Type A larvae). The second provincular tooth from the posterior end of the right valve is enlarged (see Fig.3.40) and this can be best seen in the dorsal view. Rees (1950) recorded the enlargement of at least one provincular tooth, often at the expense of others around it, as common in Mactracean larvae. The lateral tooth appears to occur on the left valve, and is due to the alternate position of the spatulate tooth. The ligament is posterior, the ridges in the right valve and the flanges in the left valve. Widely separated concentric lamellae can be seen under polarised light, particularly over the 2nd prodissoconch shell, and there are no radial striae.

The late stage larva frequently reaches 285 μ in length with a height of 260 μ and a hinge line length of 70 μ . The late stage larva is almost circular in shape, and the umbos are knobby and equal in size. The anterior end is more pointed than the posterior end, but both are of similar length. Both shoulders are rounded, but the posterior shoulder is shorter and steeper. The ventral margin is rounded.

An early dissoconch of Paphies australe from Patone Beach is given in Fig.3.37 c, and it has a shape similar to that of the late stage Mactracean 1 larva. Fig.3.37d gives a juvenile Paphies australe. The posterior end lengthens at a greater rate than the anterior end, to give an almost symmetrical Paphies australe adult.

B. Larval distribution - Figs. 3.41 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10, and Wellington Shell Club (1969).

This larva occurred commonly in the plankton in Bay of Islands, and in greatest densities at the inner harbour stations (Confluence and Brampton Reef).

It occurred abundantly in Wellington Harbour plankton at all stations, but greatest densities occurred at the Petone Beach station.

This larva did not occur at Raumati Beach or Dargaville Beach on the west coast, but it did occur at all four northern harbours during the spring sampling (Table 3.5.) where it was often one of the most abundant bivalve larval species present.

The distribution and abundance of this larva relates well with the distribution and abundance of the adults of Paphies australe.

C. Seasonal abundance - Figs.3.35 and 3.58.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands, this larva occurred in the plankton throughout most of the sampling period, but peak occurrences were mainly during the spring and summer.

The monthly wet weight condition index cycle for adults of Paphies australe from Shelly Beach in the Kerikeri Inlet, Bay of Islands (Fig.3.3c) for 1971-72 is given in Fig.3.42. The condition index cycle followed behind the monthly mean water temperature^{curve}/by about two months. A rapid decline of condition occurred during May and June 1971. However, no features of this condition index cycle are consistent with the occurrences of Mactracean 1 larvae in the plankton. The small range and low values in the condition index curve suggest that no spawning of this population of Paphies australe took place during the observation period.

In Wellington Harbour, this larva occurred in the plankton at all times of the year, with peak occurrences during the spring, summer and autumn. During parts of spring and summer it was one of the dominant bivalve larvae present in the harbour (Fig.3.58). Mr.T.G.Biggs (pers.com.) reported dense settlements of Paphies australe spat on Petone Beach in November 1970, which was consistent with the spring peak of Mactracean 1 larvae in the plankton about this time.

At the four northern harbours (Table 3.5) this larva was one of the

most abundant present during the spring and summer sampling periods.

MACTRACEAN 2

? Spisula aequilateralis (Deshayes)

A. Description - Figs. 3.38 and 3.40.

The larval shape most closely fits the Mulinia grouping of Sullivan (1948) and the Mactrid (Spissula solidissima) grouping of Miyazaki (1962).

The late stage larval hinge (Fig. 3.40 left valve) is most similar to the Mactracean Type C hinge of Rees (1950). There is a Type c provinculum, and the ligament is posterior. In larvae greater than 280 μ in length, a small spatulate tooth occurs at the anterior end of the left valve.

The late stage larva often reaches 295 μ in length, with a height of 295 μ and a hinge line length of 85 μ .

The umbos of the late stage larva are equal in size and knobby. The anterior end is much more pointed, and is slightly longer than the posterior end. The anterior shoulder is steeper, longer and more rounded than the posterior shoulder. The ventral margin is rounded.

This larva is very similar to the line drawing of Spisula subtruncata of Jorgensen (1946) and the photomicrographs of Spisula solidissima of Sullivan (1948) and Spisula elliptica of Rees (1950). These similarities help to confirm this identification.

B. Larval distribution and seasonal abundance.

Table 3.5. Fig. 3.41

Refer to adult abundance Tables 2.9 and 2.10 and Wellington Shell Club, (1969).

This larva occurred only at Raumati Beach, where it was one of the most abundant bivalve larvae present in the plankton during the summer of 1972, although it did also occur at other times of the year.

The occurrence of this larva in the plankton is consistent with the distribution of the adults of Spisula aequilateralis, which occur abundantly on open coasts only. More prolonged plankton sampling

at Dargaville Beach would probably have also taken this larva.

MACTRACEAN 3. ? Scalpomactra scalpellum (Reeve)

A. Description - Figs. 3.39 and 3.40.

The larval shape most closely fits the Mulinia grouping of Sullivan (1948) and the Mactrid (Mactra veneriformis) group of Miyazaki (1962).

The late stage larval hinge (Fig. 3.40, right and left valves), has both Mactracean Type A and Mactracean Type C (Rees, 1950) features. The ligament is posterior, the provinculum is Type c, but the large spatulate tooth at the anterior end of the left valve is a Mactracean Type A feature. (The spatulate tooth can be seen in Fig. 3.40. It projects in towards the shell centre, and so it is best seen in dorsal view). The ridges and flanges are thin and difficult to determine, but the flanges do appear to occur on the left valve, and the ridges on the right, which is consistent with Mactracean larvae.

The late stage planktonic larva is large, frequently reaching 500 μ in length, with a height of 480 μ and a hinge line length of 80 μ .

The umbos of the late stage larva are equal in size and knobby. The anterior end is more pointed, and slightly longer than the posterior end. The posterior shoulder is more rounded and shorter than the anterior shoulder. The ventral margin is rounded.

Under polarised light, radial striae are visible, particularly towards the outer 2nd prodissocench shell (Fig. 3.39b). Concentric lamellae are usually more obvious on the inner prodissocench 2 shell, where they are not so obscured by the radial striae. The prodissocench 1 shell is quite clearly delineated from prodissocench 2 under polarised light.

The larva most closely resembles Mactrid E of Rees (1950).

B. Larval distribution - Figs. 3.41 and 3.58.

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10 and Wellington Shell Club (1969).

This larva occurred most commonly in the plankton at Bay of Islands, where it occurred frequently or occasionally at all three plankton stations.

In Wellington Harbour it was rarely encountered.

It occurred only occasionally at Raumati Beach, and at Mahurangi.

C. Seasonal abundance - Figs.3.41 and 3.58.

Tables 3.3, 3.4 and 3.5.

This larva occurred during the springs of both years in Bay of Islands.

In Wellington Harbour it occurred in winter 1971, and summer 1971-72, but the larval occurrences were too low to deduce seasonal trends.

FIGURES
3.37, 3.38 and 3.39

FIGURE 3.38

MACTRACEAN 1

? Paphies australe (Gmelin)

- (a) group of late stage larvae (average length 280 μ)
- (b) single valves of late stage larva (280 μ length)
- (c) early dissoconch shell of Paphies australe
- (d) juvenile Paphies australe

FIGURE 3.39

MACTRACEAN 2

? Spisula aequilateralis (Deshayes)

- (a) group of late stage larvae (average length 296 μ)
- (b) single valve of late stage larva (295 μ length)

FIGURE 3.40

MACTRACEAN 3

? Scalpomactra scalpellum (Reeve)

- (a) group of late stage larvae (average length 450 μ)
- (b) single valve of late stage larva (480 μ length).

Photomicrograph taken under polarised light to show the concentric lamellae and radial striae.

MACTRACEA

Mastracean 1

FIG. 37

a

b

c

d

Mastracean 2

38

a

b

Mastracean 3

39

a

b

1. Mactracean 1. ? Paphies australe (Gmelin)

Upper: right valve of late stage larva of 285 μ length.

st = spatulate tooth.

t = group of 2-3 enlarged provincular teeth
(see text).

Lower: left valve of late stage larva of 270 μ length.

l = ligament

lt = lateral tooth.

2. Mactracean 2. ? Spisula aequilateralis (Deshayes)

Left valve of late stage larva of 270 μ length.

l = ligament

t = Type c provincular tooth (see Rees, 1950)

3. Mactracean 3. ? Scalpomactra scalpellum (Reeve)

Upper: right valve of late stage larva of 480 μ length.

lt = lateral tooth

l = ligament.

Lower: left valve of late stage larva of 480 μ length

l = ligament

st = spatulate tooth.

MACTRACEAN HINGES

FIG. 40

Maत्रacean

1

2

MACTRACEAN HINGES
con t

Mastracean
3

FIG. 40 con t

FIG.3.41 Seasonal variations of abundance of late stage bivalve
larvae in Bay of Islands and Wellington Harbour -
 MACTRACEA

Mactracean 1 ? Paphies australe (Gmelin)

Mactracean 3 ? Scalpomactra scalpellum (Reeve)

The plankton sampling area and station are given
with each abundance curve.

FIG. 41

MACTRACEA

Maetracean 1

NO. OF LARVAE PER 1000 L

Maetracean 3

FIGURE 3.42

FIGURE 3.42. Paphies australe (Gmelin)

The wet weight condition index cycle (see Section 3, Methods) for twentyfive animals per month from Shelly Beach, Bay of Islands (Fig.3.3C).

The vertical lines give the range in condition index values of the five groups of five individuals analysed. Mean values are joined.
For further explanations, see Text.

The monthly mean seawater temperatures for Bay of Islands are from Table 1.3.

FIG. 42

SUPERFAMILY ADESMACEA

I. Adult distribution - (refer to Tables 2.5, 2.9 and 2.10,

Beu and Climo, 1971, and

Wellington Shell Club, 1969)

Powell (1961) recorded two families of this superfamily occurring in New Zealand:

(1). Pholadidae, represented by two genera with three species. The most common and widespread species is Barnea similis (Gray) occurring frequently in Bay of Islands, and uncommonly in Wellington Harbour and on west coast areas.

(2) Teredinidae. Powell (1961) recognized two genera with two species in NZ, but this family is at present under review. Also, the larval life histories of the members are being currently studied.

II. Larval characteristics -

The Pholad larva features have received relatively little attention in the literature. Jorgensen (1946), Chanley (1965a) and Chanley and Andrews (1971) reviewed the descriptions of larval Pholads. The feature most common to all the descriptions is the circular or near-circular larval shape, and the short hinge line (Chanley and Andrews, 1971).

The larval hinge form was described by Werner (1939), Jorgensen (1946) and Rees (1950) and confirmed by Chanley (1965a).

The Teredinid larval features have received much more attention in the literature. Larval Teredinid descriptions were reviewed by Jorgensen (1946), Rees (1950), and Chanley and Andrews (1971). All Teredinid larvae have a spherical shape, high, steeply slanting, narrow shoulders, narrow, knobby umbos, and short, sharply curved ventral margins. The larval hinge structure has been described by Sigerfoos (1907), Jorgensen (1946), Rees (1950), Scheffema (1971) etc.

III. Common New Zealand Adasmacean larvae -

One common late stage larva was recognized as a Pholad by its hinge structure and larval features.

At least two common late stage larvae from the Bay of Islands plankton samples were recognized as Teredinid larvae.

PHOLAD 1. ? Barnea similis (Gray)

A. Description - Figs.3.43 and 3.47.

The late stage larval hinge (Fig.3.47, right and left valves) has several typical Pholad features. The right valve has a long, broad central tooth, and a smaller tooth at the posterior end of the hinge line. The left valve has a large central insert, a smaller tooth at each end of the insert, and a further small insert at the posterior end of the hinge line. The ligament is posterior, the flanges are on the left valve, and the ridges are on the right valve. There are no lateral teeth or special teeth. This hinge system closely resembles that described for the Pholadidae by Jorgensen (1946), Rees (1950), Chanley (1965a) and Chanley and Andrews (1971), except that in Pholad 1 the reduced tooth in the right valve occurs at the posterior end of the hinge line instead of the anterior end, and therefore its corresponding indentation on the left valve is also at the posterior end.

The late stage larva usually reaches 300 μ in length, with a height of 310 μ and a hinge line length of 100 μ .

The umbos in the late stage larva are equal in size, pointed and knobby, projecting above an almost circular larva. The ends are equal in length, the shoulders narrow and rounded. The posterior shoulder is slightly higher than the anterior shoulder. The ventral margin is almost circular.

The larva is strong and heavy, dark coloured, and often has a dark band around the outer prodissococh 2 shell margin. There is no pigmented eyespot.

The larva closely resembles the drawing by Werner (1939) and photomicrograph by Sullivan (1948) of Zirphaea crispata, and the

photomicrographs by Chanley (1965a) and Chanley and Andrews (1971) of Barnea truncata.

B. Larval distribution and seasonal abundance -

Tables 3.3, 3.4 and 3.5.

Refer to adult abundance Tables 2.9 and 2.10, and Wellington Shell Club (1969).

This larva occurred occasionally in plankton samples from Bay of Islands and in greatest densities at the inner harbour stations (Confluence and Brampton Reef).

Although its seasonal occurrence was not plotted, it was most commonly observed during the late winter and spring of both 1970 and 1971.

It occurred less frequently in the plankton in Wellington Harbour and at Raumati Beach.

These larval occurrences are consistent with the occurrence of the adults of Barnea similis.

TEREDINIDS 1, 2 and 3 (?)

Only brief mention is made of the Teredinid larval species observed in the Bay of Islands plankton samples since the larval development of the New Zealand species are at present being studied.

A. Descriptions - Figs. 3.44, 3.45, 3.46 and 3.47.

The shapes of the three late stage larvae fit the Teredo grouping of Sullivan (1948) and the Teredinid group of Miyazaki (1962).

The late stage larval hinge of Teredinid 1 is given in Fig. 3.47, and is very similar to that given for Teredinids by the previously-mentioned authors. The left valve has a large central depression to accommodate the central tooth of the right valve. The two smaller teeth in the left valve fit into the slots in the right valve. The two depressions in the left valve accommodate teeth from the right valve.

Teredinid 1 is the largest of the three larvae, usually reaching

250 μ in length, with a height of 225 μ and a hinge line of 80 μ length. It is oval in shape and almost symmetrical, and has small, slightly knobby umbos of equal size. The shoulders are high, rounded and narrow, and one is slightly higher than the other. The ends are of equal length, and the ventral margin is sharply rounded. The larva is strong and heavy, dark in colour, and often has a purplish tinge around the umbo area. A dark concentric band, with a lighter band to the outside of it ^{is} often seen in the outer prodissocoenoch 2 shell. (Fig.3.44b). There is no pigmented eyespot.

Teredinid 2 is smaller than Teredinid 1, usually up to 200 μ length and 225 μ in height. It is oval in shape, almost symmetrical, and has a more knobby umbo than Teredinid 1. The shoulders are high, rounded and narrow, and the ventral margin is less pointed than in Teredinid 1. Often there is a purplish tinge in the umbo region, and a dark band in the outer prodissocoenoch 2 shell. There is no pigmented eyespot.

Teredinid 3 (?) is of a similar size to Teredinid 2, but is less circular in shape, and the umbos are more angular.

McQuinn (1964) recorded only two Teredinid species at Opua, Bay of Islands (Fig.1.3) viz., Lyrodus medilobata and Bankia australis. Since Teredinid 1 and 2 are definitely Teredinid larvae, the family grouping of Teredinid 3 remains questionable.

B. Seasonal abundance - Figs.3.56 and 3.58.

Teredinid 1 late stage larvae occurred in greatest densities in the Bay of Islands plankton during midsummer and throughout the winter, but they did occur in the plankton throughout most of the year.

Teredinid 2 larvae also occurred in the Bay of Islands plankton throughout most of the year.

Teredinid 3 (?) was encountered only occasionally in Bay of Islands plankton samples.

UNIDENTIFIED BIVALVE LARVAE

Seven bivalve larvae which occurred frequently or occasionally in the Bay of Islands and Wellington Harbour plankton samples are given in Figs.3.48 - 3.54. No attempt is made to describe or identify those in Figs.3.50 - 3.54; their photomicrographs have been included for the sake of completeness.

UNIDENTIFIED LARVA 1.

A. Description - Figs.3.48 and 3.55.

The shape of this late stage larva does not adequately fit any of the groupings of Sullivan (1948) or Miyazaki (1962).

The late stage larval hinge (Fig.3.55, both valves) does not adequately fit any hinge-types described by Rees (1950). The hinge is strong and heavy, and has a Type c provinculum, with no lateral teeth or special teeth. The left valve has a large central tooth, which inserts into a depression in the right valve. The depression just posterior to the central tooth in the left valve is the insert for the tooth of the right valve. The flanges are on the left valve, and the ridges are on the right valve.

The late stage larva usually reaches 325 μ in length, with a height of 260 μ and a short hinge line of 80 μ length.

The late stage larva is almost equilaterally triangular in shape, and the umbos are angular and equal in size. The ventral margin is broadly rounded, almost flat.

The larva is yellowish in colour, and is strong and heavy. No pigmented eyespot occurs.

Prominent concentric lamellae occur over the larval shell, particularly over the 2nd prodissocoenoch shell. A very prominent outer concentric line, which does not coincide exactly with the concentric lamellae, occurs in the 2nd prodissocoenoch shell. This line is clearly seen in whole larvae under normal lighting (see Fig.3.48 a and b).

There are no radial striae.

B. Larval distribution - Figs.3.57 and 3.58.

Tables 3.3, 3.4 and 3.5.

This larva occurred frequently in Bay of Islands plankton samples at all three plankton stations.

It also occurred frequently in plankton samples taken in outer Bay of Islands areas and was abundant in samples taken 5 miles south east of Cape Brett on 12/1/72. (see Fig.1.3).

It occurred occasionally, sometimes frequently, in the Wellington Harbour plankton, with least densities at the Petone Beach plankton station. This larva also occurred off Raumati Beach, often commonly.

C. Seasonal abundance - Figs.3.57 and 3.58.

Tables 3.3, 3.4 and 3.5.

In Bay of Islands, this larva occurred throughout most of the year, but with the greatest peak occurrence during the spring of 1971.

In Wellington Harbour it occurred sporadically, particularly during 1971.

At Raumati Beach it occurred in the plankton throughout the year, except in late summer and autumn.

UNIDENTIFIED LARVA 2 (Figs.3.49 and 3.55)

The larval shape is typical of Pandoracean larvae (Chanley, 1969.). Chanley and Castagna (1966) reviewed observations on Pandoracean larvae, and concluded from their own laboratory rearing experiments that the identifications of Pandoracean larvae by Rees (1950) and Stafford (1912) were incorrect, although that of Sullivan (1948) was correct.

The main features of Pandoracean larvae are the oval D-shaped form, with a slight indentation towards the centre, and the dark grey to black colouration. Sullivan (1948) stated that the hinge teeth oppose each other, while Chanley and Castagna (1966) stated that there are no

identifiable teeth present in the larval shell, but that there is a large u-shaped ligament.

Unidentified larva 2 usually reaches 220 μ in length, with a height of 170 μ . The larva is strong and heavy, dark coloured, and a prominent central eyespot 5 - 7 μ across develops in larvae 200 μ or more in length.

The larval hinge has two teeth at each end of the hinge line, and is opposed by two inserts and three teeth in the other valve (Fig.3.55)

This larva was observed only at the inner Bay of Islands plankton stations (Confluence and Brampton Reef) during late May 1970. It occurred abundantly in the top 4m of water at this time.

The most abundant Pandoracean bivalves in Bay of Islands are the Myadora species, so this may be the larva of Myadora striata (Quoy and Gaimard).

FIGURES**3.43, 3.44, 3.45 and 3.46**

FIG.3.43

PHOLAD 1

? Barnea similis (Gray)

- (a) group of late stage larvae (average length 300 μ)
- (b) single valve of late stage larva (300 μ length)
showing concentric line in the outer prodissoconch 2 shell.

FIG.3.44

TEREDINID 1

- (a) group of late stage larvae (average length 250 μ)
- (b) single late stage larva (250 μ length)
showing band in the outer prodissoconch 2 shell.
- (c) single valves of late stage larva (250 μ length).

FIG.3.45

TEREDINID 2

Late stage larva at 210 μ length.

FIG.3.46

TEREDINID 3 (?)

Late stage larva (?) at 200 μ length.

Pholad 1

FIG. 43

a

Teredinid 1

44

a

b

c

Teredinid 2 45

Teredinid 3 (?) 46

FIGURE 3.47 Late stage larval hinges - ADESMACEA

Pholad 1. ? Anchomasa similis (Gray)

Upper: right valve of late stage larva of 290 μ length

Lower: left valve of late stage larva of 290 μ length

t = tooth.

Teredinid 2

Upper: right valve of late stage larva of 250 μ length.

Lower: left valve of late stage larva of 250 μ length.

ADESMACEAN HINGES

FIG. 47

Pholad 1

Teredinid 1

FIGURES

**3.48, 3.49, 3.50, 3.51,
3.52, 3.53, & 3.54**

FIG.3.48 UNIDENTIFIED LARVA 1.

- (a) group of late stage larvae (average length 320 μ)
- (b) single valve late stage larva (325 μ length)

Note the prominent concentric line in the outer
prodissocoenoch 2 shell.

FIG.3.49 UNIDENTIFIED LARVA 2

- (a) group of eyed late stage larvae (average length 220 μ)
- (b) single valve of late stage larva (220 μ length)

FIG.3.50 - 3.54

Other unidentified late stage larvae from Bay of Islands
and Wellington Harbour plankton collections.

Larva 1 FIG. 48

Larva 2 49

Larva 3 50

Larva 4 51

Larva 5 52

Larva 6 53

Larva 7 54

FIGURE 3.55

Late stage larval hinges - UNIDENTIFIED LARVAE

Unidentified larva 1

Upper: left valve of late stage larva of 320 μ length.

i = indentation

t = tooth.

Lower: right valve of late stage larva of 320 μ length.

Unidentified larva 2

Left and right valves of late stage larva of 220 μ length

i = indentation

t = tooth.

UNIDENTIFIED LARVAE -
HINGES

Larva 1

FIG.55

Larva 2

FIGURES**3.56 and 3.57**

Seasonal variations of abundance of late stage
bivalve larvae in Bay of Islands and Wellington
Harbour

FIGURE 3.56

ADESMACEA

Teredinid 1

FIGURE 3.57

UNIDENTIFIED LARVAE

Unidentified larva 1.

FIG. 56

ADESMACEA

Teredinid 1

NO. OF LARVAE PER 1000L

57 UNIDENTIFIED LARVAE

Larva 1

SEASONAL ABUNDANCE OF BIVALVE LARVAE

Most bivalve larval species which occur in Bay of Islands also occur in Wellington Harbour, the main exceptions including Crassostrea glomerata and Anomia walteri, which occur commonly only in Bay of Islands.

The variations in the relative abundance of the late stage bivalve larvae occurring commonly in the Bay of Islands and Wellington Harbour plankton samples are summarised in Fig.3.58. These diagrams should be read in conjunction with the species abundance graphs given with each superfamily.

Table 3.6 summarises the observations on the seasonal occurrence of the late stage bivalve larvae in the Bay of Islands and Wellington Harbour plankton samples. The frequency of sampling makes it possible to determine only the broadest patterns of occurrence of the larvae.

There is much variation in the seasonal occurrence of different species of bivalve larvae. Several species occur commonly in the plankton throughout the year, but occur abundantly once or twice during the year. For example, Mactracean 1 (Paphies australis) in Wellington Harbour, and the incubatory species Kellia cycladi formis and Lasaea rubra hinemoa in Bay of Islands, and ? Arthritica bifurca in Bay of Islands and Wellington Harbour.

Other species occur occasionally or frequently in the plankton throughout the year, but occur commonly or abundantly at least once during the year. For example, Pectinid 1 (? Chlamys (Mim.) zelandiae) in Wellington Harbour, Teredinid 1 in Bay of Islands, and Leptonacean 1 in Bay of Islands and Wellington Harbour.

Other species occur in the plankton only twice during the year, commonly or abundantly, and usually during the spring and late summer or autumn. For example, Venerid 4 in Bay of Islands, and Atrina pectinata zelandica in Wellington Harbour.

Some species occur in the plankton at one time of the year only, for example Venerid 1 (? Chione stutchburyi) occurs only during spring

TABLE 3.6. Summary of observations on the peak occurrences of late stage bivalve larvae in the Bay of Islands and Wellington Harbour plankton samples.

The occurrences are the pooled results for 1970-71 and 1971-72 from Figs.3.12, 3.18, 3.28, 3.29, 3.35, 3.41, 3.56, 3.57, and 3.58.

For the occurrence of other species in the plankton, including those from Raumati Beach, see Text and Tables 3.3, 3.4 and 3.5.

Late stage larva	Provisional identification.	Bay of Islands	Wellington Harbour
Mytilid 1	<u>Mytilus edulis aoteanus</u>	Aug - Nov.	May - Oct Dec - Jan
Mytilid 2	<u>Modiolus areolatus</u>	May - Sep Nov - Dec Feb - Mar	
Mytilid 3	<u>Perna canaliculus</u>	Sep - Oct	Jul - Oct Dec - Feb May
Mytilid 4	<u>Xenostrobus pulex</u>	Aug - Oct	small amount in Jul - Oct
Mytilid 5	<u>Modiolarca impacta</u>	Most of year, including mainly Jun - Jan. Mar.	Aug - Sep Dec - Feb Apr - Jun
<u>Atrina zelandica</u>			Jan - Mar May - Jun
Pectinid 1	<u>Chlamys (Mimachlamys) zelandiae</u>	Jul - Oct	May Jul - Nov
<u>Anomia walteri</u>		Dec - Mar or April	
<u>Ostrea sp.</u>		Dec - May (swarming)	
<u>Crassostrea glomerata</u>		Dec - Mar or April	
<u>Kellia cycladiformis</u>		Swarming most of year, but mainly Jun - Sep Nov - Jan	Most of year, but mainly Apr - Jun

TABLE 3.6 (contd.)

Late stage larva	Provisional identification.	Bay of Islands	Wellington Harbour.
<u>Lasaea rubra hinemoa</u>		Swarming most of year, but mainly Sep - Oct Feb - Mar	
	<u>Arthritica bifurca</u>	Swarming all year, but mainly Apr - Jun Dec - Feb.	Swarming all year, but mainly Apr - Jun Dec - Feb
Leptonac ean 1	? <u>Borniola reniformis</u>	Most of year, mainly Dec - Feb	Dec - Feb Apr - Jun
Venerid 1	<u>Chione stutchburyi</u>	Sep - Dec	Aug - Sep (?) Dec - Feb Apr - Jun
Venerid 2	<u>Dosinia lambata</u>	Aug - Nov Jan Mar	Aug - Sep Nov - Jan May - Jul
Venerid 3	<u>Tawera spissa</u>	Jan - May	Jan - Feb Apr - Jul
Venerid 4		Aug - Oct (major) Feb - Apr	
Mastracean 1	<u>Paphies australe</u>	Most of year, mainly Aug - Jan	Most of year, mainly Apr - May Aug - Oct Dec - Feb
Mastracean 3	<u>Scalpomactra scalpellum</u>	Aug - Nov.	
Teredinid 1		Dec - Feb. Apr - Sep	
† larva 1		Most of year	Small numbers most of year.
? larva 2		May	

in Bay of Islands, while Anomia walteri, Ostrea sp. and Crassostrea glomerata occur only during the summer or during the summer and early autumn in Bay of Islands.

In general, the spawning seasons of bivalves in Bay of Islands are shorter and more defined than those in Wellington Harbour. This can be seen in the greater symmetry of Fig.3.58A than 3.58B.

Fig.3.59 gives the variation in total late stage larvae and total D-shaped larvae in Bay of Islands and Wellington Harbour plankton samples during 1970-71. In both harbours the density of D-shaped larvae exceeded the density of late stage larvae at most times of the year, but ^{the} times of maximum and minimum densities of late stage larvae and D-shaped larvae usually coincided.

In Bay of Islands, late stage and D-shaped larval densities were high throughout the year, but peaks occurred in the autumn and spring of both years, and in the mid-summer of 1970-71.

In Wellington Harbour, larval densities were more variable, although larval peaks (both late stage larvae and D-shaped larvae) occurred at approximately the same times of the year as they did in Bay of Islands. However, the summer peak (1970-71) in Wellington Harbour was about one month earlier, and was more marked than in Bay of Islands. The spring 1971 peak was about one month later, although the spring 1970 peak occurred at about the same time as in Bay of Islands.

These times are generally consistent with those given by Jillet (1971) who recorded total bivalve larvae at two stations in Hauraki Gulf. He found bivalve larvae to be most abundant in early to midspring and early summer during 1963-4, although he did not record an autumn peak.

Other studies overseas (e.g. Le Bour, 1933, 1947) have also reported total bivalve larvae usually being most abundant during spring, summer and autumn.

FIGURE 3.58

Variations in the relative abundance of the major
bivalve larval species in Bay of Islands (upper)
and Wellington Harbour (lower)

Figure 3.58 is a blank area, likely representing the missing figure content.

FIG. 58

A BAY OF ISLANDS

B WELLINGTON

FIGURE 3.59

Monthly abundance of total late stage bivalve larvae
(continuous line)
and total D-shaped larvae (broken line)
for Bay of Islands (upper) and Wellington Harbour (lower)

Values are the average for the plankton stations.

FIG. 59

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SECTION 4

OBSERVATIONS
ON THE ECOLOGY
OF THE
BIVALVE LARVAE
OF
BAY OF ISLANDS
AND
WELLINGTON HARBOUR,
NEW ZEALAND

SUMMARY

Ecological studies made on bivalve larvae at Bay of Islands and Wellington Harbour during 1970-1971, are presented and compared to other published studies from overseas.

Included are observations on the vertical meso-distribution of bivalve larvae over tidal cycles in estuarine and non-estuarine localities of 12m to 15m depth, the daytime vertical meso-distribution of bivalve larvae in non-estuarine water 20m - 30m in depth, the effect of light on the vertical meso-distribution of bivalve larvae in water 15m - 30m in depth, and the horizontal mega-distribution of bivalve larvae in Wellington Harbour and Bay of Islands.

The observations suggest that in estuarine areas, the effect of alternating tides on the vertical distribution of bivalve larvae far outweighs the effects of any other factors. During the flood tide bivalve larvae rise from the bottom into the water column, and are carried up the estuary by the tide. During the ebb tide the larvae settle and remain on the bottom.

In non-estuarine areas, no such vertical migration was observed. Gravity, light and water currents, in particular, affect the vertical distribution of bivalve larvae in these areas.

The horizontal mega-distribution of bivalve larvae within Wellington Harbour is fairly uniform. In Bay of Islands, bivalve larvae occur in greatest densities near the shores, while much of the central basin is almost devoid of larvae. This distribution is due to the proximity of the adult stocks to the regions of most larvae, and to the prevailing water current pattern within the bay.

INTRODUCTION

This paper considers the ecological observations made on bivalve larvae in Bay of Islands and Wellington Harbour during 1970-71, and compares these observations with those of other published studies overseas.

Historical Background -

Hefford (1947), Yaldwyn (1957), and Jillett (1971) have reviewed the studies made on the zooplankton in New Zealand, most of which have largely dealt with the distribution of the plankton, or some component of it, in time, rather than in space. There have been few zooplankton studies in New Zealand from an ecological aspect.

Published plankton studies from Bay of Islands are limited to occasional plankton collections earlier in the century (e.g. Farran, 1929).

Plankton studies from Wellington Harbour have included those of Stuckey (1948), Bary and Stuckey (1950), Bary (1951, 1952), Johannesson (1955), Johannesson and Martin (1955, 1956), Maxwell (1956), R.M. Cassie (1957, 1959a, 1959b, 1960, 1963) V. Cassie (1960), Norris (1964) and Wear (1965)

Ecological studies on bivalve larvae

Ecological studies on bivalve larvae are usually arduous because of the smallness of the larvae (70 - 400 μ in length), and the problem of species identification. Few New Zealand bivalve larvae have been identified and there are no published ecological studies on New Zealand bivalve larvae. Dawson (1954) discussed aspects of the larval ecology of Amphidesma (Paphies) subtrianqulatum and Rainer (1966) of Crassostrea glomerata, both in unpublished theses.

Most of the ecological studies on bivalve larvae overseas have dealt with commercially important bivalve species, mainly oysters. The most important reviews of these studies have included those of Korringa (1941), Galts off (1964) and Verwey (1966).

Distribution of bivalve larvae

The random distribution of organisms in space is rare, and an "aggregated" pattern is more common (Cassie, 1957); Winsor and Clarke (1940), Barnes and Marshall (1951) etc. reported these aggregations in plankton populations. It would therefore appear likely that bivalve larvae will commonly have an aggregated, non-random distribution.

R.M.Cassie (1960) found that the pattern-forming agencies determining the observed spatial non-random distribution of a plankton species could be divided into four categories:

- 1 - Chance (or random factors)
- 2 - The physical environment (correlations with temperature, salinity, etc.)
- 3 - The influence of other species.
- 4 - Internal behaviour patterns within the species.

Components of the physical environment which could cause the non-random distribution of bivalve larvae include gravity, hydrostatic pressure, light, currents, water temperature, salinity, turbidity, hydrogen ion concentration, dissolved oxygen content, etc.

The influence of other species include predator-prey relationships, and attraction and repulsion by other species.

Internal behaviour patterns within the species include attraction and repulsion between individuals of the same species, and release of gametes during spawning.

The resulting distribution patterns may be of different magnitudes. R.M.Cassie (1958) described horizontal mega-distributional, meso-distributional and micro-distributional patterns in plankton populations. (Mega-distribution is a spatial distribution which can be detected by sampling intervals of greater than 100m, but it does not include geographical distribution. Meso-distribution can be detected by sampling intervals not less than 1m and not greater than 100m. Micro-distribution can be detected by sampling intervals of less than 1m)

Few studies have been made on the micro-distributional patterns of bivalve larvae, the most notable being that of Carriker (1951), who sampled the vertical distribution of oyster larvae in shallow New Jersey estuaries with sampling intervals of 0.2m.

The horizontal and vertical meso-distribution of bivalve larvae have been more widely studied overseas, and reference will be made to some of these studies.

SAMPLING AREAS

Observations were made at Bay of Islands and Wellington Harbour during 1970-71. The physiography and hydrology of the two harbours have been previously described (Section 1). The main sampling stations are given in Figs.4.1 and 4.2, but further stations will be referred to later.

METHODS

1. Hydrological measurements -

The methods of hydrological measurements were described in Section 1, Methods (pages 4 - 7).

2. Plankton collections -

(A). Most plankton collections were made with a WP₂ free-fall net (described in Section 3, pages 138 to 142). The vertical distribution of bivalve larvae was determined by one of two divided net drop methods:

(i) A series of drops were made with the WP₂ net from the surface to progressively greater depths in the water column, and the larval concentrations in any part of the column determined by subtraction.

(ii) A bridle arrangement for the WP₂ net was constructed (Fig.4.3). The net was lowered upside down to $\frac{1}{2}$ metre

FIGURES

4.1, 4.2, 4.3

FIGURE 4.1.

BAY OF ISLANDS

Some plankton sampling stations

1. Confluence.	4. Bird Rock.
2. Brampton Reef.	5. Cape Brett
3. Waewaetoria.	6. Wairiri Rock.

FIGURE 4.2

WELLINGTON HARBOUR

Some plankton sampling stations

1. Mahanga Bay	3. Petone Beach
2. S.W. Somes Island.	4. Ngauranga.

FIGURE 4.3.

WP₂ NET WITH BRIDLE

Steps in the operation of the WP₂ net determining the plankton in a particular section of the water column. (See page 265).

FIG. 1

2

3

above the required depth, turned over and allowed to fall the required distance.

After each drop, particular care was taken to wash the plankton down the net to the collecting bucket, generally by dropping the throttled net through 10 or 15 m of water, and then by moving the net up and down in the water before hauling aboard.

The usual time interval between successive plankton samples in any one series was about 3 minutes.

(B). Surface tows of a set duration were made with a 45 cm. mouth diameter conical net of square 100 μ mesh.

2. Laboratory procedures -

Plankton samples were preserved, and treated in the laboratory in the same manner as described in Section 3.

PRESENTATION OF DATA

The results of surveys and transects of larval occurrences and densities in Bay of Islands and Wellington Harbour are presented, together with a discussion of them. Frequent reference is made to the hydrological data from both harbours which was given in Section 1. Bivalve larvae occurring in the plankton samples were described in Section 3.

OBSERVATIONS AND DISCUSSION

1. VERTICAL DISTRIBUTION OF BIVALVE LARVAE OVER THE TIDAL CYCLE

The effect of several hydrological parameters in causing non-random distributions of bivalve larvae can be studied by observing changes in the vertical distribution of bivalve larvae over a tidal cycle.

Several observations were made on the vertical distribution of bivalve larvae during the tidal cycle in Bay of Islands and Wellington Harbour, but only one was continued for more than one complete tidal cycle. The observations are summarised in Table 4.1.

TABLE 4.1.

TIDAL CYCLE STUDIES

Area	Station	Date	Stages of tide sampled	Depths sampled.
Bay of Islands.	Confluence	29/7/70	LT - $\frac{1}{2}$ T - HT	0 - 5m) 5 - 10m) WP ₂ net 10m - bottom)
	Confluence	8-9/2/71	$\frac{1}{2}$ T - LT - $\frac{1}{2}$ T - HT - $\frac{1}{2}$ T - LT - $\frac{1}{2}$ T - HT - $\frac{1}{2}$ T - LT	0 - 5m) 5 - 10m) WP ₂ net 10m - bottom)
Wellington Harbour	Mahanga Bay	16/8/70	$\frac{1}{2}$ T - HT - $\frac{1}{2}$ T	0 - 5m) 5 - 9m) WP ₂ net 9 - 14m)
	Mahanga Bay	20/1/71 25/1/71	$\frac{1}{2}$ T - HT - $\frac{1}{2}$ T - LT - $\frac{1}{2}$ T - LT - $\frac{1}{2}$ T - HT	0 - 5m) 5 - 9m) WP ₂ net 9 - 14m)
	Mahanga Bay.	1/3/71	LT(day) - HT (night)	0 - 5m) 5 - 10m) WP ₂ net 8 - 13m)

There was a limit to the frequency of sampling I could manage since I was working single-handed, and was usually taking simultaneous hydrological measurements. (Ideally plankton samples would have been taken at least two-hourly from each depth.) Furthermore, the time required to analyse the plankton samples from these tidal studies was enormous, and so restrictions had to be placed on the total number of samples taken. In each case, I recorded the occurrence of total bivalve larvae, total late stage bivalve larvae, an estimate of the total D-shaped bivalve larvae, and also the occurrence of the individual species of late stage bivalve larvae that occurred frequently enough to warrant it.

(usually about six species).

A. Tidal cycle survey at Confluence, Bay of Islands, 8-9/2/71

The results of the main Bay of Islands tidal cycle plankton study (8 - 9/2/71) are given in Fig.4.4, and simultaneous hydrological observations over the first complete tidal cycle are also recorded.

The water temperature, salinity, and dissolved oxygen did not vary much during the tidal cycle, and there was little vertical stratification of these parameters. (Fig.4.4A, B and D). The incoming water was slightly warmer (up to 0.7°C) and slightly more saline (up to $0.2^{\circ}/\text{oo}$) than the outgoing water. Maximum water temperature occurred at about half flood tide, with the water column isothermal at 22.9°C . Maximum salinity occurred after half flood tide, with surface waters during the incoming tide up to $0.15^{\circ}/\text{oo}$ more saline than the bottom waters.

Current velocities generally increased with depth. Highest current velocities occurred just after half tide during both the ebb and the flood tides, with the maximum velocity occurring during the flood tide.

The hydrological structure of the Confluence station on 8/2/71 was compared with the structure on 29/7/70, deduced from a similar, although shorter, survey. The data are given in Fig.4.5. The survey began one hour before low water, and continued until one and a half hours after high water.

The general hydrological features are very similar to those for the flood tide on 8/2/71. Water temperatures on 29/7/70 (Fig.4.5.) had a slightly greater range (approximately 1.6°C) than on 8/2/71, but the incoming water was warmer on both days. On 8/2/71, surface temperatures were slightly higher than bottom temperatures, but on 29/7/70 the inverse applied (because of the lower winter air temperatures). Salinities were lower on 29/7/70 than on 8/2/71, and had a greater range during the incoming tide (more than $1.0^{\circ}/\text{oo}$), with maximum salinity occurring just

FIGURE 4.4.

TIDAL CYCLE SURVEY AT CONFLUENCE PLANKTON STATION
BAY OF ISLANDS
8 - 9/2/71

A - F. Distribution against time of some hydrological parameters during 8/2/71.

A. Temperature ($^{\circ}\text{C}$). Isotherms at 0.2°C . intervals.

Temperatures are given at the depths of the measurements.

B. Salinity ($^{\circ}/\text{oo}$). Isohalines at $0.05^{\circ}/\text{oo}$.

Salinities are given at the depths of the measurements.

C. Relative current velocity. Isolines at 5 unit intervals.

Filled circles denote the depths of the measurements.

D. Per cent oxygen saturation. Values are given at the depths of the measurements.

E. Water turbidity (Secchi Disc visibility values, in metres).

F. Wind velocity (estimated)

L - M = Light to moderate wind.

The wind was from the East throughout the day.

Subsurface water samples were obtained with a Petersen water bottle.

Temperatures were measured with a mercury thermometer accurate to better than 0.1°C .

Salinities were determined against standard seawater with a Beckman RS7B salinometer in the laboratory. Relative current velocities were measured with the mounted TSK flow meter (see Section 1, Methods, page 7). Per/cent oxygen saturation values were determined by the $\frac{O_a}{O_b} \times 100$ relationship (see Section 1, Methods, page 6), with O_b values taken from Truesdale and Gameson (1956). Water turbidity was measured with a plain white Secchi disc.

FIG. 4

8-2-71

FIGURE 4.4 (contd.) TIDAL CYCLE SURVEY AT CONFLUENCE PLANKTON STATION
BAY OF ISLANDS
8 - 9/2/71

G - J. Vertical distribution against time of some bivalve larvae during
8 - 9/2/71.

G. Total number of late stage bivalve larvae.

Figures give the number of larvae per 10 litres of water.

Isolines at 1 larva per 10 litres of water intervals.

H. Estimated total D-shaped bivalve larvae.

Figures give the number of larvae per liter of water.

Isolines at 2 larvae per litre of water intervals.

I. Number of late stage larvae of ? Arthritica bifurca (Fig.3.25b)

over 280 μ in length. Figures give the number of larvae per
1000 litres of water. Isolines at 25 larvae per 1000 litres
of water intervals.

J. Number of late stage larvae of Venerid 3 (Fig.3.32) over

230 μ in length. Figures give the number of larvae per 10 lit
of water. Isolines at 1 larva per 10 litres of water interval

The larval distributions are derived from three drops of the WP₂
net (0 - 5m, 5 - 10m, and 10m - bottom). Filled circles mark the central
point of each drop of the net.

At high tide the water depth was 15m. At half tide it was
approximately 14m, and larval numbers for the net drop 10 - 14m were
multiplied by a factor of 1.25, so as to give the number of larvae taken
had it been a 5m drop. Similarly, at low tide, when the water depth was
approximately 13.5m, larval numbers for the net drop 10 - 13.5m were
multiplied by a factor of 1.4. A 5m drop of the WP₂ net filters
approximately 1000 litres of water.

8 & 9-2-71

before half flood tide. There was no marked salinity stratification, with values increasing only slightly with depth. Maximum current velocities occurred just after half flood tide on both days, and current velocities generally increased with depth. Percent oxygen saturation was high during both days. Water turbidities, as measured by the Secchi disc, were higher on 29/7/70 than on 8/2/71, and on both days increased towards high tide.

Isopleths of the vertical distribution of some bivalve larvae during the two tidal cycles on 8-9/2/71 are given in Fig.4.4. E - J. Other late stage larvae not graphed, but which showed identical vertical distributional patterns, included Anomia walteri (Fig.3.16) Ostrea sp. and Crassostrea glomerata (see Section 3, Ostreacea), and Kellia cycladi formis (Fig.3.20).

The main features of the isopleths are the upward movement and increased density of larvae in the water column from the beginning of the flood tide, with this distribution persisting until high tide slack water. The larvae then settled to the bottom, and remained on the bottom during the ebb tide and the low tide slack water. The pattern was repeated on the flood tide at night, but with a slightly greater upward movement of the larvae.

The greatest upmovement of larvae during the first tidal cycle coincided with the period of the highest water salinities, temperatures and current velocities during the flood tide (Fig.4.4, A and B), but more frequent sampling would have been necessary to have determined the exact time of the upward movement of the larvae. The current velocities during the ebb and flood tides (Fig.4.4C) seem too similar to have been the cause of such marked differences in the vertical distribution of the bivalve

larvae between the flood and ebb tides.

If the larvae remain on the bottom during the ebb tide, and at low tide slack water, but rise in the column during the flood tide and remain there until the end of the high tide slack water, this would be evident in the densities of larvae for the whole water column over the tidal cycle. A series of WP₂ net drops from the surface to the bottom were made coincident with the series of divided drops on 8-9/2/71. The results for total bivalve larvae, total late stage bivalve larvae, total D-shaped bivalve larvae, as well as four individual species of late stage bivalve larvae, are plotted in Fig.4.6. Six other species of late stage bivalve larvae (Mytilid 5, Fig.3.10, Anomia walteri, Fig.3.16, Kellia cycladi formis, Fig.3.20, Leptonacean 1, Fig.3.26 Mactracean 1, Fig.3.37 and Pholad 1, Fig.3.43) had similar patterns.

The graphs show that larval densities on the flood tide frequently exceeded those on the ebb tide, and low tide slack water, by up to 100%. This correlates well with the behaviour of bivalve larvae shown in Fig.4.4 (G - J).

A shorter, less frequent series of WP₂ drops from the surface to the bottom was made at the Confluence station on 4/2/71. The results are given in Fig.4.7. Larval densities on the flood tide exceeded those on the ebb tide and at low tide slack water by about 100%, and are therefore in general agreement with the observations given in Fig.4.6.

I

FIGURES

4.5, 4.6 and 4.7.

FIG.4.5. TIDAL CYCLE SURVEY AT CONFLUENCE PLANKTON STATION,
BAY OF ISLANDS
29/7/70

Distribution against time of some hydrological parameters.

- A. Temperature ($^{\circ}\text{C}$). The discontinuous line gives temperature at the surface, the continuous line gives temperature at 8m depth, and the dotted line gives temperature at 14m depth.
- B. Salinity ($^{\circ}/\text{‰}$) at surface, 8m and 14m depth as for temperature.
- C. Relative current velocities at surface, 8m and 14m depth as for temperature.
- D. Per cent oxygen saturation values at surface, 8m and 14m depth as for temperature.
- E. Water turbidity (Secchi Disc visibility values in metres).
- F. Wind velocity (estimated)

L = light. m = moderate. s = strong.

The wind was from the southwest throughout the day.

Subsurface water samples were obtained with a Petersen water bottle.

Temperatures and salinities were measured with an RH5 salinometer (see Section 1, Methods, pages 5 and 6).

Relative current velocities were measured with a mounted TSK flowmeter (see Section 1, Methods, page 7).

Per cent oxygen saturation values were determined by the $\frac{O_a}{O_b} \times 100$ relationship (see Section 1 Methods, page 6), with O_b values taken from Truesdale and Gameson (1956)

Relative turbidities were measured with a plain white Secchi Disc.

FIG.4.6. TIDAL CYCLE SURVEY AT CONFLUENCE PLANKTON STATION,
BAY OF ISLANDS
8 - 9/2/71

Distribution against time of some bivalve larvae. The graphs give the number of larvae per 1000 litres of water for the WP₂ net drop from the surface to the bottom (approximately 15m).

1. Total bivalve larvae (estimated)
2. Total D-shaped bivalve larvae (estimated)
3. Total late stage bivalve larvae.
4. Late stage Mytilid 5 larvae (Fig.3.10) over 270 μ length.
5. Late stage Mactracean 1 larvae (Fig.3.37) over 260 μ length.
6. Late stage Ostrea sp. larvae (see section 3, Ostreacea)
over 280 μ length.
7. Late stage Kellia cycladiformis larvae (Fig.3.20)
over 300 μ length.
8. Late stage Anomia walteri larvae (Fig.3.16) over 220 μ in length.
9. Late stage ? Arthritica bifurca larvae (Fig.3.25) over 280 μ length.
10. Late stage Crassostrea glomerata larvae (see Section 3, Ostreacea)
over 280 μ length.
11. Late stage Leptonacean 1 larvae (Fig.3.26) over 350 μ length.
12. Late stage Venerid 3 larvae (Fig.3.32) over 230 μ length.
13. Late stage Pholad 1 larvae (Fig.3.43) over 270 μ length.

FIG.4.7.

TIDAL CYCLE SURVEY AT CONFLUENCE PLANKTON STATION,
BAY OF ISLANDS
4/2/71

Distribution against time of some bivalve larvae.

Figures give the number of larvae per 1000 litres of water
for the WP net drop from the surface to the bottom
²
(approximately 15m).

1. Total late stage bivalve larvae.
2. Total bivalve larvae (estimated)
3. Late stage larvae of Anomia walteri larvae
(Fig.3.16) over 220 μ length.
4. Late stage larvae of ? Arthritica bifurca larvae
(Fig.3.25) over 280 μ length.

FIG. 6

FIG. 7

The data show that a change in the direction of the tide at the Confluence station may produce some change, although usually small, in the relative proportion of different species of bivalve larvae present. But usually the same species remain the most abundant on both the flood and the ebb tides. Therefore, a plankton sample taken at any stage of the tide will give a fair indication of the relative abundance of the different bivalve larval species present, although the absolute densities of individual species may be different at different stages of the tide.

The limitations of these observations on the vertical migration of bivalve larvae at the Confluence must be emphasised. Only one station was sampled, the frequency of sampling was low, and the vertical migration patterns were observed only on one occasion (two tidal cycles), although the bivalve larvae in the whole water column over a tidal cycle were observed on two different occasions.

It is also true that divided collections made to determine the vertical distribution of plankton often have large sources of error, and this explains the discrepancies between the larval densities for the divided drops for the vertical column, (Fig.4.4 G - J), and those for the single drops from the surface to the bottom, (Fig.4.6), made at the same time. Barnes (1949) analysed the divided hauls of Marshall, Nicholls and Orr, (1934) and Marshall (1949), whose collections were made with a modified international net fitted with a Nansen closing mechanism. They used hauls of approximately 10 metres length, and Barnes found that the coefficient of variation of a single observation was in the order of 90%. Barnes suggested that this was due to an accumulation of small errors of technique, including the opening and closing device being inefficient, and that these weighted the results heavily when only a small column of

water was sampled.

The net used in this study has been found to accept 95% of the water presented to it (Smith, Counts and Clutter, 1968) and the opening and closing method (described earlier) is different to that used in the study analysed by Barnes (1949). Although I made no tests, I consider it to be very unlikely that there was more than a 30% variation in the length of the planned 5M drops of the net in this present study, and therefore the coefficient of variation of the single observations could be expected to be of an order of less than 90%. In any case, a coefficient of variation in the order of 90% does not account for the 200-300% variations in larval densities often observed between different stages of the tide. (Fig.4.4 G-J). Furthermore, the occurrence of two consecutive, direct observations on bivalve larvae rising vertically from the bottom in the water column on the flood tide seem unlikely to be pure chance observations, merely due to the variability between divided hauls.

B. Other Tidal Cycle Studies. (see Table 4.1).

No tidal cycle surveys of bivalve larvae of this nature were carried out at the other two plankton stations in Bay of Islands (Brampton Reef and Waewaetoria - Fig.4.1). Both of these stations are in much more open water with smaller tidal cycle salinity variations, and neither is a point in the up-estuary travel of larvae. (See Section 1, Hydrology, for general hydrological features of these two stations. In particular, see under Discussion - temperatures and salinities). Although larvae will still undoubtedly undergo some vertical migration (due to varying currents, light conditions etc.), some changes in density with tides, and also show some completely chance variations, I would expect overall variations in larvae densities and composition to be much less than those at the Confluence station. Short term observations on larval densities and

composition at these two stations in January 1971 indeed showed small variations, but little weight can be placed on these results because of the brief and infrequent sampling.

Sampling during the other tidal cycle studies (Table 4.1) was not as prolonged as that at the Confluence, although it was of similar frequency.

The survey at the Confluence station, Bay of Islands, on 29/7/70 yielded very low numbers of bivalve larvae.

In the January 1971, Mahanga Bay (Wellington Harbour) tidal cycle survey, the salinities over the tidal cycle varied by approximately $8.1^{\circ}/\text{oo}$, and the currents were about half the strength of those of the Confluence surveys. No clear pattern of vertical movement of bivalve larvae was apparent. Greatest larval concentrations occurred in the water column at low tide slack water, but they were not maintained during the flood tide, nor did the larvae rise vertically in the water column.

In the August 1970 survey at Mahanga Bay, greatest numbers of larvae occurred at the two half tides, with smaller larval densities at high tide slack water. Larvae were generally in a higher position in the water column during the flood tide.

There was little change in the vertical distribution of bivalve larvae between the slack waters at low tide (daytime) and high tide (nighttime) at Mahanga Bay in March 1971. The most marked difference was the lack of larvae in the top 5M of the water column during the daytime low tide slack water, and the slightly more even distribution of larvae in the water column at the high tide slack water at nighttime.

These results have important applications to the theories of the colonization of estuaries by bivalve species beyond the point that tidal

effects alone would be expected to give. The main reviews of these theories on estuary colonization include those of Korringa (1941), Carriker (1951), Galtsoff (1964), Haskin (1964), Verwey (1966) and Wood and Hargis (1971).

In summary there are two main schools of thought. One suggests that larvae have control over their vertical distribution in the water column. It is the product of early observations by J.Nelson, and later his son T.C.Nelson (1954), on oyster larvae in New Jersey estuaries, and is supported in particular by Carriker (1951), Kunkle (1957), Haskin (1964), and Wood and Hargis (1971). All these authors suggest that bivalve larvae can move up estuaries by swimming upwards from the bottom on the flood tide after being stimulated by the increased salinity, (and possibly also by the increased current velocity), and by remaining on the bottom during the ebb and low water slack tides.

The second school maintains bivalve larvae have little control, if any, over their vertical movements, and are moved up and down estuaries passively by the tides. Korringa (1941) maintained that oyster larvae in the Oosterschelde were generally uniformly distributed in the vertical watercolumn, and underwent no tidal migrations, although he did emphasise that eyed larvae just prior to settlement may not be uniformly distributed. Loosanoff (1949) found no general relation between the stratification of larvae and the tidal changes in his observations in Long Island Sound and Milford Harbour in United States of America. Andrew (1954) considered too much emphasis had been given to the activity of the larvae, and too little to the physical system of currents, tides, wind and turbulence, in explaining the colonization of estuaries.

Other workers have not needed the vertical migration of larvae to explain observed larval distributions. For example, Moore and Marshall (1967), concluded that tidal effects alone could explain the presence of bivalve larvae well up the Niantic Estuary (U.S.A.)

Variations to both schools exist. Some workers maintain some concept of vertical migration of bivalve larvae, but of a different type than that proposed by the first school, e.g. Prytherch (1928), Cole and Knight Jones (1949), Yasuda (1952), Dew and Ferguson Wood (1955), Medcof (1955) and Verwey (1966). The observations of Yasuda (1952) and Dew and Ferguson Wood (1955) on vertical migration during tidal cycles are for pooled larvae, without investigating any one species in particular, and therefore the data is of limited value.

The results of the tidal cycle surveys at the Confluence station in Bay of Islands support the first school. However, the Wellington Harbour observations show ^{ed}no similar marked ^{upm}ovement of larvae during the flood tide, and so do not conform to that school.

The small differences between the salinity variations observed at Mahangap Bay and Confluence over tidal cycles, and yet quite marked difference in the vertical behaviour of bivalve larvae at the two stations, suggests some factor other than salinity may be important in stimulating the vertical migration in bivalve larvae.

Mahanga Bay does not have the estuarine character of the Confluence, and has slightly smaller salinity differences between flood and ebb tides. It therefore seems possible that estuaries have a downflowing "estuarine element", which stimulates larvae to sink during ebb tides. Such an element may be a product of processes and metabolism in the estuary. Most of the overseas studies which have shown similar vertical movements of bivalve larvae to those observed at the Confluence were made in wholly shallow estuarine environments, e.g. the studies of J. Nelson in New Jersey estuaries, Carriker (1951) in New Jersey estuaries (including Barnegat Bay) and Wood and Hargis (1971) in the James River estuary in Chesapeake Bay

(where salinities varied by up to 2.5^0 /oo during the tidal cycle).

Kerringa (1941), however, working in the Oosterschelde, which is not truly estuarine, found no correlation between the vertical distribution of oyster larvae and the state of the tide. Similarly, the observations of Loosanoff (1949) in Long Island Sound were not in true estuarine environments.

2. EFFECT OF GRAVITY ON THE DAYTIME VERTICAL DISTRIBUTION OF BIVALVE LARVAE

Since bivalve larvae are more dense than seawater, gravity is an important factor in determining their vertical distribution in the water column. Some larvae show geotaxis, and there may be variation in the actual geotactic response among different species of bivalve larvae, and at different stages of larval development (Verwey, 1966).

The observations on the vertical distribution of bivalve larvae over the tidal cycle at the estuarine Confluence plankton station in Bay of Islands (given in Fig.4.4) show that the tide, with its inherent change in water temperature, salinity, current velocities etc., has far more influence on the vertical distribution of bivalve larvae than does any other factor. The bivalve larvae are stimulated by tidal factors to oppose or supplement their normal responses to light and hydrostatic pressure, and to oppose or supplement the effects of gravity.

But in non-estuarine waters, variations in the hydrological parameters associated with tides are far smaller, and the influence of other factors, such as gravity and light, upon the vertical distribution of bivalve larvae become important.

Some observations were made during 1970-71 on the vertical distribution of bivalve larvae in non-estuarine water over 12m and up to 30m in depth in Bay of Islands and Wellington Harbour. Prolonged velar swimming is required to oppose gravity and maintain a position high in the water column if no upwelling currents are operating, so these observations can shed light on the extent of the control bivalve larvae have on their vertical distribution.

- A. Fig.4.8 gives the vertical distribution of bivalve larvae, including observations on four individual species of late stage larvae, at South West Somes Island, Wellington Harbour (Fig.4.2) at 1100 hours (low tide slack water) on 25/2/71 under an overcast sky. The vertical distribution was determined using WP₂ net drops: 0 - 5m, 5 - 10m, 10 - 15m and 10 - 22m. Greatest larval concentrations occurred at regions of highest salinity and

lowest temperature, but the overall governing factor is probably gravity, causing the greatest density of larvae in the bottom 7 metres of the water column. This applied to all individual species considered, and to both D-shaped and late stage forms. However, the presence of some larvae in the top 5 metres of the water column indicates some larvae are able to counter-act gravity by velar swimming.

- B. A series of WP₂ net plankton samples were taken at Ngauranga plankton station in Wellington Harbour (Fig.4.2) in 22 m of water on 24/11/70. Samples were taken at high tide slack water (1315 - 1330 hours) in clear sunny conditions with a light southerly wind and a light sea chop. Using the WP₂ net drops 0 - 5m, 5 - 10m, 10 - 15m and 15 - 20m, it was found that bivalve larvae occurred in greatest numbers in the 0 - 5m and 10 - 15m sections of the water column, and lowest in the bottom 10 - 15m. Eyed Mytilid 1 larvae (Fig.3.6) were concentrated in the middle area of the column from 5 to 15 depth.

A thermocline existed between 2 to 6m, with a drop of 1.5°C, and larval numbers were greatest both above and below the thermocline area, but the numbers of larvae were insufficient to prove that this distribution was caused by thermocline.

- C. Two vertical series of WP₂ net plankton samples were taken within an hour of each other over high tide slack water at Mahanga Bay, Wellington Harbour during the mid-afternoon of 16/7/70. There was a moderate north-westerly wind, skies were cloudy, and the sea surface was choppy.

In the first series of samples, the D-shaped larvae were most abundant in the upper half of the water column, while later stages were more abundant in the lower half. In the second series, larvae of all stages were concentrated in the lower third or two-thirds of the water column, although some did occur at all depths. Eyed Mytilid 1 larvae (Fig.3.6) were exceptional in that they were concentrated in the bottom third only.

- D. Fig.4.9 shows the vertical distribution of bivalve larvae at the South West Somes Island plankton station in Wellington Harbour (Fig.4.2)

The vertical distribution was determined using the WP₂ net drops 0 - 5m, 5 - 10m, 10 - 15m, and 10 - 22m. These were taken in bright sunshine at 1100 hours (half flood tide) on 28/9/70.

Lowest numbers of larvae occurred between 8 and 16m water depth, but Arthritica bifurca was exceptional in that it occurred in greatest densities in this depth range.

The percentage of larvae present in the top 8m of water usually equalled or exceeded that in the bottom 8m of water, except in the case of eyed Mytilid 1 larvae, which occurred in much greater numbers in the bottom 8m than in the top 8m of the water column.

E. WP₂ net drops (0 - 15m and 0 - 30m) were made near Cape Brett, Bay of Islands (Fig.4.1) in 30m of water, during the ebb tide at mid-day on 28/4/71. There was a light chop and the sky was clear. The vertical distribution of total bivalve larvae and total D-shaped bivalve larvae, as well as that of three individual species of late stage bivalve larvae, (Atrina pectinata zelandica, Fig.3.14, Mytilid 2, Fig.3.7, and Unidentified larva 1, Fig.3.48) were analysed. All had similar vertical distributions, with greatest larval densities (about 75% of total) in the upper half of the water column.

F. In a series of three WP₂ net drops (0 - 10m, 0 - 20m, and 0 - 30m) taken 1 mile northwest of Bird Rock, Bay of Islands (Fig.4.1) two hours before low tide (1415 hours) during bright sunshine on 28/4/71, late stage and D-shaped bivalve larvae were found distributed throughout the whole column, but more species and greater larval numbers occurred nearer the surface.

The observations do not show a simple accumulation of larvae near the bottom of the water column due to gravity, as Quayle (1953) reported for Bankia setacea larvae in Pendrell Sound. Although the series of observations cover only a few of the possible sea and sky conditions, it is apparent that bivalve larvae seldom, if ever, completely withdraw from upper regions

FIGURES
4.8 and 4.9

The vertical distribution of bivalve larvae at South West Somes Island (see Fig.4.2) at low tide slack water on 25.2.71

Plankton samples were taken with the WP₂ net between 1045 and 1105 hours.

1. Total bivalve larvae.
2. Total D-shaped bivalve larvae.
3. Early staged larvae of Atrina pectinata zelandica (Fig.3.14) of the length range 145 μ to 250 μ .
4. Late stage larvae of Atrina pectinata zelandica greater than 300 μ in length.
5. Late stage larvae of Mytilid 5 (Fig.3.10) greater than 270 μ in length.
6. Late stage larvae of ? Arthritica bifurca (Fig.3.25) greater than 270 μ in length.
7. Late stage larvae of Leptonacean 1 (Fig.3.26) greater than 350 μ in length.

The total number of larvae for each species for the 22mdrop (4312 l) is given below each vertical distribution diagram.

Temperatures ($^{\circ}$ C.) were taken with the Murayama Electronic thermometer. (See Section 1, Methods, page 5).

Salinities ($^{\circ}$ /oo) were determined with a Beckman RS7B salinometer calibrated against standard seawater.

A moderate northwest wind was blowing during the sampling, producing a moderate surface chop. The sky was overcast.

Secchi Disc visibility value was 3.5m.

The vertical distribution of bivalve larvae at South West
Somes Island (see Fig.4.2) at low tide slack water on 28/9/70

Plankton samples were taken with the WP₂ net between 1120 and
1130 hours.

1. Total D-shaped larvae.
2. Total late stage bivalve larvae.
3. Late stage larvae of Mactracean 1 (Fig.3.37)
greater than 260 μ in length.
4. Late stage larvae of ? Arthritica bifurca (Fig.3.25)
greater than 270 μ in length.
5. Late stage larvae of Mytilid 1 (Fig.3.6) greater than
260 μ in length.

T Temperature ($^{\circ}$ C.) was taken with the Murayama Electronic
thermorecorder.

The total number of larvae for the 24m drop (47041) is given below
each vertical distribution diagram.

A strong north west wind was blowing, giving a very choppy sea surface.
Skies were clear.

FIG. 8

FIG. 9

of non-estuarine waters up to 30m in depth during daylight hours.

There is probably almost constant velar swimming by the larvae to counteract gravity and to maintain their level in the water column. When currents are maximal, usually during flood and ebb tides, larvae may be assisted by currents and upmoving eddy currents. When tidal currents are minimal at slack water, larvae tend to sink deeper in the water column.

There was some evidence of variation in the geotactic responses among different species of bivalve larvae. For example, the eyed late stage Mytilid 1 larvae (? Mytilus edulis aoteanus) were often found deeper in the water column than other species of larvae in Wellington Harbour. Overseas studies have reported similar phenomena. For example, Manning and Whaley (1954) reported late stage oyster larvae occurring at greater depths than the earlier stages.

3. EFFECT OF LIGHT ON THE VERTICAL DISTRIBUTION OF BIVALVE LARVAE

Any observation on the vertical distribution of bivalve larvae over more than two tidal cycles in areas with semidiurnal tides will yield simultaneous information on the response of the larvae to tidal effects, and to the diel cycle.

The observations on the vertical distribution of bivalve larvae over two tidal cycles at the Confluence station in Bay of Islands on 8-9/2/71 (Fig.4.4) indicate that, although the stage of tide is the main factor determining the vertical distribution of bivalve larvae, the extent of the vertical upmovement of the larvae may be greater at night time.

Similarly, the series of plankton samples taken at slack tides during daytime and nighttime on 1/3/71 at Mahanga Bay in Wellington Harbour (see Table 4.1 and page 278) showed a more even distribution of bivalve larvae within the water column at night-time than at daytime.

Although there has been much published in the literature on the diurnal vertical migration of planktonic animals, particularly Crustacea, there have been few observations on the effect of the diel cycle on the vertical migration of bivalve larvae. However, there have been a number of observations on the effect of short term light variations on different species of bivalve larvae. Thorson (1964) listed bivalve species which show phototaxis during larval life.

Korringa (1941) reviewed the work done up to this time on the effects of light on bivalve larval ecology, and, in particular, its effect on oyster larvae. He concluded from his own field observations that day-light and bright-dull sequences had little effect on the vertical distribution of bivalve larvae. Quayle (1953) also found no diurnal movements of *Bankia setacea* larvae during three days of sampling.

The late stage eyed larvae, however, become photonegative just prior to settlement. Verwey (1966) noted the accumulation of late stage Mytilus edulis larvae at the water surface at night, while at the same time younger larvae moved downwards towards the bottom.

In summary, the present results are similar to those of Carriker (1961) for Venus mercenaria, in that there is a broader distribution of most bivalve larval species in the water column at night-time, but that there is no marked diurnal migratory behaviour. The effects of alternating tides, at least in estuarine areas, have a greater influence than light on the vertical distribution of bivalve larvae.

Although individual species of bivalve larvae may have different responses to light at different stages of development, the tidal survey at the Confluence (Fig.4.4) suggests that D-shaped larvae have almost the same reaction as the late stage larvae to both tidal changes and to the effect of nightfall. This comment, general to the bivalve larvae as a whole as well as to several particular species, is in disagreement with the particular studies of Bayne (1964) and Verwey (1966) on Mytilus edulis larvae.

4. HORIZONTAL MEGA-DISTRIBUTION OF BIVALVE LARVAE IN WELLINGTON HARBOUR.

The plankton of Wellington Harbour, like the hydrological regime (Section 1), is well mixed. Analysis of the graphs for the seasonal abundance of bivalve larvae species at the four Wellington Harbour stations given in Section 3 show that most late stage larvae occur in similar densities at all four stations at any one time. Only the early products of localised spawnings may be expected to have marked horizontal mega-distributional patterns, since some period of time is required for the products to be assimilated into the harbour system.

Further evidence of the degree of mixing of the plankton in the harbour was derived from two series of two minute plankton tows made at several points around Wellington Harbour during 1970. The stations are given in Fig.4.10.

On 19/3/70 there was a strong southerly wind, rough seas, and cloudy, wet conditions, while on 12/5/70 there was no wind, the sea was calm, and the skies clear.

Sampling on each day was completed within two hours, and weather and sea conditions were constant during the sampling periods on both days.

Late stage larvae occurring abundantly (more than 50 larvae per tow), are given in Table 4.2.

On 19/3/70 the composition and density of the plankton samples was very consistent in five out of the six stations. The first station, at the harbour entrance, was low in larval numbers and density, probably because of the tendency for larvae to be washed out of the harbour.

The series of tows on 12/5/70 had few larvae, and species diversity was low throughout the harbour. The station at the mouth of the Hutt River (station e) had no larvae.

Although the series of surface tows do not necessarily represent the larvae occurring in the vertical column, they are indicative of the degree of homogeneity in the harbour at any one time. The present results help confirm that the plankton of Wellington Harbour is generally well mixed.

5. HORIZONTAL MEGA-DISTRIBUTION OF BIVALVE LARVAE IN BAY OF ISLANDS.

Observations were made in Bay of Islands during 1971 on the horizontal mega-distribution of bivalve larvae.

- A. The sampling stations of the first transect, sampled on 5/2/71, are given in Fig.4.11A. The WP₂ net was dropped from the surface to the bottom at stations 1 - 7, and to 100 metres at stations 9 - 16 (Fig.4.11B) Fig.4.11C gives the surface temperatures and salinities for the transect, while Fig.4.11 D - I give the distribution of bivalve larvae, including the distribution of eight individual species of late stage bivalve larvae. The densities of the total bivalve larvae, total late stage bivalve larvae, total D-shaped bivalve larvae, as well as late stage larval species 4 - 5

TABLE 4.2.

WELLINGTON HARBOUR

Late stage bivalve larvae taken in 2 minute net tows during two harbour surveys. (See Fig.4.10 for station positions).

<u>19/3/70.</u>	<u>Station</u>	<u>Late stage larvae</u>
	1	Mytilid 5*, Mactracean 1
	2	Mytilids 1* and 5*, ? <u>Arthritica bifurca</u> , Venerid 1
	3	Mytilids 1* and 5*, ? <u>Arthritica bifurca</u> , Mactracean 1*.
	4	Mytilids 1*, 3 and 5*, ? <u>Arthritica bifurca</u> , Mactracean 1*.
	5	Mytilids 1*, 3 and 5*, ? <u>Arthritica bifurca</u> Pectinic 1, Mactracean 1*, Venerid 1.
	6	Mytilids 1* and 3, ? <u>Arthritica bifurca</u> , Venerid 1, Mactracean 1*.
	7	Mytilids 1* and 3, Venerid 1, Mactracean 1*.

* Most abundant species.

12/5/70

Very few larvae at any stations.

FIGURE 4.10

WELLINGTON HARBOUR

Surface tow stations on 19/3/70 (open circles), and 12/5/70 (filled circles)

FIGURE 4.11.

BAY OF ISLANDS

The distribution and density of bivalve larvae in a transect of the harbour on 5/2/71.

- A gives the stations.
- B gives the depth of the WP₂ net drops (m) and the water depths (m).
- C gives surface temperatures (°C.) and surface salinities (‰).
Temperatures were taken with a mercury thermometer calibrated to 0.1°C, salinities were determined with a Beckman RS7B salinometer against standard seawater.
- D - I gives the distribution and density of some bivalve larvae.
 - 1. Total Bivalve larvae.
 - 2. Total late stage bivalve larvae.
 - 3. Estimated total D-shaped bivalve larvae.
 - 4. Mactracean 1 (Fig.3.37) greater than 260 μ in length.
 - 5. Leptonacean 1 (Fig.3.26) greater than 350 μ in length.
 - 6. Mytilid 2 (Fig.3.7) greater than 280 μ in length.
 - 7. Unidentified larva 1 (Fig.3.48) greater than 270 μ in length.
 - 8. Anomia walteri (Fig.3.16) greater than 220 μ in length.
 - 9. Kellia cycladiformis (Fig.3.20) greater than 300 μ in length.
 - 10. Ostrea sp. (see Sec.3, Ostreacea) greater than 280 μ in length.
 - 11. Unidentified larva 3 (Fig.3.50) greater than 270 μ in length.

FIG. 10

FIG. 11

and 8 - 11 (all in Fig.11 D - I), fell off rapidly from station 1 to station 5. Other species of late stage bivalve larvae whose densities fell off rapidly from station 1 to station 5, but which are not given in Fig.4.11, included ? Arthritica bifurca (Fig.3.25), Teredinid 1 (Fig.3.44), and Crassostrea glomerata (see Sec.3, Ostreacea).

Two species of bivalve larvae (Mytilid 2 and Unidentified Larva 1 in Fig.4.11 G) occurred commonly at stations 2 to 9, with maximum densities at stations 4 to 8.

In summary, the transect showed that greatest densities of bivalve larvae occurred near the shore, that few bivalve larvae occurred in the main basin, and very few or none occurred outside the bay.

B. Two further transects of Bay of Islands in February 1971, verified this distribution of bivalve larvae. The transect stations and results are given in Fig.4.12. The transect on 14/2/71 (Transect A) was made between 1100 and 1330 hours during the ebb tide, while that on 16/2/71 (Transect B) was made between 0900 and 1100 hours on the flood tide. Single drops of the WP₂ net were made from the surface to the bottom, or to 46m. The depths of the drops are given with each transect, and the larval density is expressed as the number of larvae per 1000 litres of water.

The densities of bivalve larvae (total bivalve larvae as well as that of most late stage bivalve larval species) were again low in the mid-basin area. Larval densities at station 6 at the eastern end of Transect B, were also low, possibly because the station was positioned only 30 metres from the shore.

The late stage larvae Mytilid₁ and 2, Kellia cycladiformis, Ostrea sp. and Mactracean 1 occurred in greater densities at one or both ends of both the transects. Even Unidentified Larva 1 (Fig.3.48) occurred in greatest densities at one end (the eastern) of both transects. (c.f. Fig. 4.11)

The distribution and density of bivalve larvae in two transects of the harbour in February, 1971.

The transects and stations appear on the map.

Transect A on 14/2/71 during the ebb tide.

Transect B on 16/2/71 during the flood tide.

The depth profiles, with the WP₂ net drops, are given with each transect.

Other graphs give the distribution and density of the bivalve larvae:

1. Total bivalve larvae.
2. Total late stage bivalve larvae.
3. Mytilid 5 (Fig.3.10) greater than 270 μ in length.
4. Mytilid 2 (Fig.3.7) greater than 280 μ in length.
5. Kellia cycladiformis (Fig.3.20) greater than 300 μ in length.
6. Ostrea sp. (See Sec.3, Ostreacea) greater than 280 μ in length.
7. Mactracean 1 (Fig.3.37) greater than 260 μ in length.
8. Identified larva 1 (Fig.3.48) greater than 270 μ in length.

FIG. 12

TRANSECT 14-2-71

A

TRANSECT 16-2-71

B

C. An analysis was made of the late stage larval species which occurred commonly (10 - 100 larvae per 1000 litres of water) or abundantly (more than 100 larvae per 1000 litres of water) at some stage of their spawning cycles during 1970 - 71, at the three plankton stations sampled in Section 3 (Confluence, Brampton Reef and Waewaetoria). The data are given in Table 4.3.

Most species of bivalve larvae occurred commonly or abundantly at some time during the sampling period at each of the three quite widely separated plankton stations. The larvae show a much less restricted distribution in Bay of Islands than do the adults, (See Table 2.9), which therefore suggests that the water and the plankton occurring at the three stations is quite well intermixed.

The three series of results suggest that the bivalve larvae occur most commonly near the shores of the bay, and in these regions, the plankton is quite well intermixed. Much of the central region of the bay is virtually devoid of bivalve larvae.

This mega-distributional pattern could be caused by several factors :

TABLE 4.3

BAY OF ISLANDS

Bivalve larvae which occurred commonly or abundantly
at the three plankton stations (Fig.3.3C) at some
time during 1970 - 1971

	<u>Confluence</u>	<u>Brampton Reef</u>	<u>Waewaetoria</u>
Mytilid 5 (Figs.3.10 and 3.12)	✓	✓	✓
<u>Anomia walteri</u> (Figs.3.16 and 3.18)	✓	✓	
<u>Ostrea</u> sp. (See Section 3, <u>Ostrea-</u> cea, Fig.3.18)	✓	✓	✓
<u>Kellia cycladiformis</u> (Figs.3.20 and 3.28)	✓	✓	✓
? <u>Arthritica bifurca</u> (Figs.3.25 and 3.28)	✓	✓	✓
Leptonacean 1 (Figs.3.26 and 3.28)	✓	✓	
Venerid 1 (Figs.3.30 and 3.35)	✓	✓	✓
Venerid 3 (Figs.3.32 and 3.35)	✓		✓
Venerid 4 (Figs.3.33 and 3.35)	✓	✓	✓
Macracean 1 (Figs.3.37 and 3.41)	✓	✓	
Merredinid 1 (Figs.3.44 and 3.56)	✓	✓	✓

Species occurred commonly if they were taken at densities of 10 - 100
litres
larvae per 1000/of water at some time during their spawning seasons in
1970 - 71; they occurred abundantly if larval densities exceeded 100 larvae
per 1000 litres of water during their spawning seasons.

- I. The bivalve larvae were present in all areas, but have been unable to survive in some because of adverse hydrological conditions.
- II. The parent stocks are close to areas of high larval concentrations, and distant from sparse concentrations.
- III. The current systems have concentrated larvae in certain regions of the bay.

Each of these possibilities is discussed:

I. Hydrological considerations - Davis (1949) and

Loosanoff and Davis (1963) concluded that bivalve larvae are quite hardy, and can withstand at least temporary exposure to a wide range of hydrological conditions. Furthermore, Calabrese and Davis (1970) suggested that larvae can in fact survive for considerable periods in conditions in which they will not actually grow.

It was concluded in Section 1 that, hydrologically, Bay of Islands is quite well mixed, particularly the main lower estuary - basin system.

The following reviews of the effects of some hydrological parameters on the survival and growth of bivalve larvae, derived mainly from laboratory experiments, suggest that little larval mortality in the main basin or lower estuary areas of Bay of Islands is due to adverse hydrological conditions.

(a) Temperature - Bay of Islands experienced greatest differences between inner and outer harbour surface temperatures during winter, when inner harbour waters were up to 2.5°C cooler than outer harbour waters (Table 1.4). During the summer, inner harbour waters were up to 2.0°C warmer than outer harbour waters (Fig.1.10)

Recent laboratory studies have shown that many larval species have a wide range of tolerance to water temperature, e.g. Loosanoff and Davis (1963) reported Mercenaria mercenaria and Crassostrea virginica larvae to have temperature ranges of up to 12.0°C at which growth

proceeded normally. Calabrese (1969) found satisfactory larval survival and growth (70% or more of optimum) for Mulinia lateralis over a 10°C range, and Davis and Calabrese (1969) gave a 12.5°C temperature range for Ostrea edulis larvae. These ranges in temperature tolerance suggest that for many species once larval development has commenced, sea temperature will influence larval survival of the species only at the extremes of the spawning season of the species.

(b) Salinity - Salinities were high and fairly constant within the main harbour system (more than $35.0^{\circ}/\text{oo}$), and only in upper estuarine areas did the salinity consistently average less than $30.0^{\circ}/\text{oo}$.

Loosanoff and Davis (1963) stated that "bivalves...display extremely wide differences in their salinity requirements and in ability to withstand sharp or gradual changes in salt content of sea water." Laboratory experiments, however, have shown that many larval species do have wide salinity tolerances. For example, Calabrese (1969) found Mulinia lateralis larvae had a $70^{\circ}/\text{o}$ or more survival over a $7.5^{\circ}/\text{oo}$ salinity range. Davis (1958) reviewed published data on the salinity tolerances of the larvae of clams and oysters, and himself found a salinity range for normal larval development of Crassostrea virginica of $15 - 17.5^{\circ}/\text{oo}$ and for Venus mercenaria of $12.5^{\circ}/\text{oo}$. Davis and Ansell (1962) found satisfactory larval development, although slowed growth, at salinities of up to $7^{\circ}/\text{oo}$ lower than normal salinity ($26 - 27^{\circ}/\text{oo}$) for Ostrea edulis larvae.

(c) Combined temperature and salinity - Recent laboratory studies have shown that the survival of a larval species may be dependent on the salinity or temperature only when the limit of tolerance of either one or the other is being approached. For example, Calabrese (1969) found that when the salinity for Mulinia lateralis was unfavourable, the range of the temperature tolerance was markedly narrowed. Brenko and Calabrese (1969) and Davis and Calabrese (1964) made similar conclusions for Mytilus edulis,

and Mercenaria mercenaria and Crassostrea virginica respectively.

These examples suggest that as the water temperature of Bay of Islands nears the limit of that required for the breeding of a species, the tolerance of the larvae to high or low salinities may decrease. But the small range in salinities within the harbour will make mortalities of larvae due to this factor small.

(d) Turbidity - Bay of Islands has a wide range of turbidity values. Secchi disc visibility values of 4 - 6m. were common in estuarine areas, while values frequently exceeded 15m in open waters (see Table 1.8 and Fig.1.13).

Loosanoff and Davis (1963) suggested that the turbidity tolerance of larvae varied greatly between species. However, the experiments of Davis and Hidu (1969) indicated that most bivalve larvae can tolerate turbidities higher than those normally encountered in natural waters, and that low concentrations of turbidity-producing materials may even be beneficial. Davis (1960) found that the growth of Venus mercenaria larvae was retarded at silt concentrations of 1 - 2.0 g/l, and at 3.4 - 4.0 g/l growth was negligible, although at 4.0 g/l no appreciable mortality occurred within 12 days. Such silt concentrations seldom occur in nature.

(e) Hydrogen ion concentrations (pH) - No observations were made on pH in Bay of Islands. Calabrese (1970) suggested that although the pH of oceanic waters may vary between 7.5 and 8.5, that of estuaries may drop as low as 7.0.

Laboratory experiments have shown that the larvae of several species have quite high pH tolerances. For example, Calabrese and Davis (1966) found pH ranges of 1.75 and 2 pH units for normal growth and development of the larvae of Mercenaria mercenaria and Crassostrea virginica respectively. Calabrese (1970) found larvae of Mulinia lateralis to survive over a 2.25 pH range.

(7) Other parameters - The most obvious chemical component, that of dissolved oxygen, has been virtually untested, although Davis (1949) suggested that oyster larvae are tolerant of at least temporary exposure to low oxygen content.

From the larval point of view, few other natural water parameters have received much attention. Davis and Chanley (1955) discussed the marked effects of some toxins on bivalve larvae in nature.

In general, the hardiness of the larvae makes them able to withstand most normal hydrological conditions within the main basin and lower estuary system of Bay of Islands. It is therefore unlikely that the observed distribution of bivalve larvae, including the low densities in the middle basin area, was due to adverse hydrological factors.

II. Proximity of parent stock -

The results of the benthic surveys in Bay of Islands (Table 2.4) suggest that the central basin of the bay has small densities of adult bivalves, while areas closer to the shore and at the mouth of the estuaries have denser populations. This distribution is consistent with that of the bivalve larvae.

Furthermore, species in Table 4.3 which did not occur at the open water Waewaetoria station are those that are largely confined to protected harbour areas, e.g. Mactracean 1 (? Paphies australe) and Anomia walteri.

Also, the adults of most of the species whose larval densities fell off rapidly in the first five stations in Fig. 4.11 are confined, or occur most abundantly, in estuarine or nearshore areas (see Table 2.9).

The exceptions were Mytilid 2, which is provisionally identified as Modiolus areolatus, and its adults are recorded in open waters (see Section 3, Mytilacea), and Unidentified Larva 1.

In summary, the proximity of the adult stock is an important factor in determining the distribution of bivalve larvae in Bay of Islands.

III. Current Systems -

The proposed current system for Bay of Islands has been presented in Fig.1.28. It consists of an anticlockwise net movement of water within the harbour.

The observed concentrations of larvae at each end of the transects in Figs.4.12 is consistent with this current system. There is a net movement of water down the Kerikeri Inlet and the Waikare Inlet (due to the freshwater inflow), with a convergence of the estuarine waters and the basin waters east of the Confluence hydrological station, and at the Brampton Reef respectively (see Figs.1.2 and 1.3). The proposed current pattern for Bay of Islands consists of the movement of at least the surface waters in opposition to the eastward flow of water from the mouth of the Kerikeri inlet. This may be the cause of the observed concentration of larvae at the western end of each transect. As the harbour current assumes its anticlockwise motion, it picks up plankton in the area off Brampton Reef, and carries it into the area of the islands around Waewaetoria, on the southern shore of the bay. This explains the concentration of bivalve larvae at the eastern ends of both transects.

If the net current movement is then along the southern shore of the bay, leaving the bay at Cape Brett, larvae of inner harbour bivalve species would be expected to occur in the Cape Brett region, and thence southwards, because of the net movement in this direction near Cape Brett (see Fig.1.15). Larval distributions of this type were observed. On two occasions during the winter of 1971, a series of WP₂ net plankton samples were taken from inside the bay and out to the Cape Brett area. The first, on 28/5/71, sampled Brampton Reef, Waewaetoria and Cape Brett stations, and a station two miles north east of Cape Brett. The second, on 29/6/71, sampled Brampton Reef, Waewaetoria, Cape Brett and Wairiri Rock.

In both surveys, the density of bivalve larvae was much less at outer stations than at the Bampton Reef and Waewaetoria stations. Also, the larvae of almost exclusively harbour species (Atrina pectinata zelandica, ? Arthritica bifurca, Kellia cycladiformis and Mactracean 1) occurred at stations in the Cape Brett region and south. This supports the proposed current pattern given in Fig.1.28. The occurrence of the larvae of Crassostrea glomerata at Cape Brett in February 1970 is further evidence of this drift.

The defined drift southwards down the coast in the Cape Brett area (Fig.1.15) makes it unlikely that the larvae observed had moved northwards from adult stocks south of the area. In any case, there are few suitable areas on the open coast immediately south of Cape Brett for these species to occur (Fig.1.4).

Also occurring commonly at the plankton stations in the Cape Brett region were the late stage larvae of Mytilids 1 and 2 and Unidentified Larva 1. The occurrence of Mytilid 2 and Unidentified Larva 1 in offshore areas has already been observed. Furthermore, it does not seem inconsistent for the larvae of Mytilid 1 (probably Modiolarca impacta, the nestling mussel) to occur in such an area since the adults can be expected to occur here.

The proposed current pattern for Bay of Islands given in Fig.1.28 does not preclude the occurrence of larvae of harbour bivalve species off the coast north of Bay of Islands. It is likely that the north-moving current off the harbour entrance may pick up larvae from the bay. The transect in February 1971 (Fig.4.11) showed no bivalve larvae in this area, (stations 10 - 15). However, three WP₂ plankton net samples at mile intervals taken on 15/9/71 from Cape Wiwiki (Fig.1.3) northwards gave the larvae of some harbour bivalve species (Mactracean 1, Venerid 1, ? Arthritica bifurca etc.) Also occurring were Mytilids 1 and 2, Teredinid 1, and Unidentified Larva 1.

Several other workers overseas have observed the distribution of bivalve larvae in relation to water currents. Churchill (1921) Roughley (1933), Elsey (1934), Elsey and Quayle (1939) and Pritchard (1952) found horizontal distributions of oyster larvae consistent with current patterns.

Larger scale horizontal movements of bivalve larvae by water currents have been also observed overseas. Mileykovskiy (1966) discussed the importance of currents in the colonization of new areas by invertebrates. In a study of the dissemination of pelagic larvae by the Norwegian current, he concluded that bivalve larvae are among the best morphologically-adapted invertebrate larvae for transport over large distances because of their considerable support surface, which allows "soaring". Furthermore, several species can undergo metamorphosis in the water column. He calculated that bivalve larvae can travel up to 600 - 720 miles in the comparatively cold waters of the Norwegian current, and actually found that Mytilus edulis larvae in the Cape Hat area had drifted up to 100 - 120 miles. Scheltema (1971) found the larvae of shipworms widely distributed in the North Atlantic Ocean, concluding that they can be carried great distances along shores and even across ocean basins. Rees (1951 and 1954) recorded Mytilus edulis larvae across much of the North Sea.

These examples suggest that the larvae of even typically protected coastline bivalve species such as Mytilus edulis aoteanus can be expected to occur in offshore plankton samples taken from around New Zealand, assuming suitable currents are present.

In summary, water currents are probably the main causes of the observed mega-distributional patterns of bivalve larvae in Bay of Islands.

CONCLUSIONS

1. In some estuarine areas, several species of bivalve larvae rise vertically in the water column during the flood tide, and sink to the bottom on the ebb tide. They are thereby carried up the estuaries. It is suggested that the increase in salinity during the flood tide may stimulate their rise in the vertical column, but that some downflowing "estuarine element" may also stimulate bivalve larvae to sink to the bottom during the ebb tide.
2. Larvae in non-estuarine water were not observed to undergo these vertical migrations. Gravity then becomes an important factor in their vertical distribution, and bivalve larvae are probably constantly swimming to counteract its effects.
3. No marked diurnal migration of bivalve larvae was observed. Night-fall seems to cause a broader distribution of most bivalve larvae in the water column.
4. Wellington Harbour plankton is quite well mixed.
5. In Bay of Islands, bivalve larvae occur in greatest numbers near the shores, while few occur in the central basin area. The observed mega-distributional patterns of the bivalve larvae are due mainly to the current system, and to the proximity of the adult stock.

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ABSTRACTS

- (1) Observations made on some hydrological parameters at Bay of Islands and Wellington Harbour during 1970-71 are presented and discussed. The parameters include water temperature, salinity, dissolved oxygen content and turbidity. The water current system in Bay of Islands is also discussed and a proposed pattern presented.

The hydrology of Bay of Islands and Wellington Harbour are compared. Bay of Islands is topographically less isolated from oceanic influence than Wellington Harbour, and there is a more marked change from estuarine to oceanic hydrological conditions within the bay.

Monthly mean surface seawater temperatures at Bay of Islands exceed those of Wellington Harbour by about 4 degrees C. Water temperature stratification is more marked in Bay of Islands than Wellington Harbour, suggesting less efficient water mixing. Salinities are lower in Wellington harbour (normally about 33.5 - 34.5 parts per thousand) than the main basin of Bay of Islands (normally about 35.5. parts per thousand). Turbidities in estuarine areas of Bay of Islands are similar to those for most of Wellington Harbour (3 - 6 metres Secchi Disc visibility values), but are much less in outer basin areas (Secchi Disc visibility values may exceed 15 metres). Dissolved oxygen content is high in both harbours, frequently exceeding 100 per cent saturation in surface water.

The results suggest that although both harbours are hydrologically quite homogeneous, Wellington Harbour is more efficiently mixed than Bay of Islands.

- (2) Benthic and shore collections of marine bivalve molluscs were made in Bay of Islands, and benthic collections were made in Wellington Harbour, during 1970 - 72. The species occurring are recorded and discussed, and the distribution of some common species in Wellington

Harbour is related to sediment types.

A list of bivalve molluscs collected in Bay of Islands is presented, and additional species to previous Wellington Harbour species lists are recorded.

Invertebrate marine communities described for New Zealand are discussed, and the bivalve fauna of both harbours is visually compared to these communities. The observations at fiftyfour anchor dredge benthic stations in Wellington Harbour are then treated statistically, and compared to the visual assessments. It appears that the great variability in Wellington Harbour sediments makes identity of classical communities in the harbour almost impossible. However, station groups (groups of stations with similar bivalve species present) are evident, and their distribution in Wellington Harbour correlate closely to sediment type distribution.

Lists of the most abundant bivalve species occurring in both harbours, deduced from all the observations presented in this study, are given.

- (3) Observations were made on the occurrence of common late stage bivalve larvae in the plankton at Bay of Islands and Wellington Harbour during 1970 - 71. Three stations in Bay of Islands and four stations in Wellington Harbour were sampled approximately monthly.

The bivalve larvae in shorter series of plankton samples from Raumati Beach, Dargaville Beach, Mahurangi, Ohiwa Harbour, Raglan Harbour and Kaipara Harbour during 1971 - 72 were also analysed.

Twentynine species of bivalve larvae from these plankton samples are described. Twenty-three species of late stage bivalve larvae are provisionally identified, the identifications being based on the larval hinge structure, the distribution and abundance of the larvae in relation to adult stocks, and in some cases by correlation

with the adult gonad or condition index cycle.

The broad seasonal pattern of occurrence of twentyfive species of late stage bivalve larvae in the plankton at Bay of Islands, Wellington Harbour and Raumati Beach is presented.

- (4) Ecological studies made in bivalve larvae at Bay of Islands and Wellington Harbour during 1970 - 71 are presented and compared to other published studies from overseas.

Included are observations on the vertical meso-distribution of bivalve larvae over tidal cycles in estuarine and non-estuarine localities of 12^m to 15^m depth, the daytime vertical meso-distribution of bivalve larvae in non-estuarine water 20^m - 30^m in depth, the effect of light on the vertical meso-distribution of bivalve larvae in water 15^m - 30^m in depth, and the horizontal mega-distribution of bivalve larvae in Wellington Harbour and Bay of Islands.

The observations suggest that in estuarine areas, the effect of alternating tides on the vertical distribution of bivalve larvae far outweighs the effects of any other factors. During the flood tide bivalve larvae rise from the bottom into the watercolumn and are carried up the estuary by the tide. During the ebb tide the larvae settle and remain on the bottom.

In non-estuarine areas, no such vertical migration was observed. Gravity, light and water currents, in particular, affect the vertical distribution of bivalve larvae in these areas.

The horizontal mega-distribution of bivalve larvae within Wellington Harbour is fairly uniform. In Bay of Islands, bivalve larvae occur in greatest densities near the shores, while much of the centralbasin is almost devoid of larvae. This distribution is due to the proximity of the adult stocks to the regions of most larvae, and to the prevailing water current pattern within the bay.