

THE ECOLOGY AND EARLY LIFE HISTORY  
OF *NOTOLABRUS CELIDOTUS* (PISCES: LABRIDAE)  
AROUND MUSSEL FARMS IN THE MARLBOROUGH SOUNDS.

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**He ika kai ake i raro, he rapaki ake i raro.**



**As the fish begins to nibble from below,  
so the ascent of a hill begins from the bottom.**

- An apt proverb of unknown origin.

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## ABSTRACT

The early life history of the labrid fish *Notolabrus celidotus* (spotties) was studied around mussel farms in the Marlborough Sounds. In both Kenepuru and Pelorus Sounds, juvenile fish (<120 mm SL) were most abundant among the shallow macro-algae of natural inshore areas. Relatively few small juveniles (<80 mm SL) were observed within mussel farms, while large juvenile and adult spotties were abundant near mooring blocks. The effect of temporal variation was only to enhance these spatial patterns. A manipulative experiment showed that some newly recruited juveniles were also closely associated with encrusting algae and sessile invertebrates on mooring ropes. However, since more than 85% of new recruits were observed in the macro-algae of natural inshore areas it appears that most spotties observed on mussel farms migrated there from inshore.

Spotties were twice as abundant in Pelorus Sound as compared to Kenepuru, possibly due to greater macro-algal habitat for juvenile development. However, the density of new recruits was inversely related to the densities of juvenile and adult fish. A plankton survey during a period of peak spawning showed that, like newly recruited spotties, egg numbers were higher in Kenepuru Sound and inversely related to the densities of juvenile and adult fish. The importance of local hydrology is discussed with regard to the abundance patterns of these early life history stages.

From histological examinations of mature spotties in both Kenepuru and Pelorus Sounds, periods of peak spawning were identified. Using age classes, growth rates of these fish were also determined. These were significantly greater in Kenepuru Sound, where densities were significantly lower.

The paucity of shallow macro-algal habitat may act as a bottleneck in Kenepuru Sound, affecting juvenile densities. After this early period of dependence on macro-algae, spotties in Kenepuru Sound appear to grow very quickly compared to those in Pelorus Sound and other areas of New Zealand.

## CHAPTER ONE

### GENERAL INTRODUCTION

#### 1.1 INTRODUCTION

##### 1.1.1 Predation of marine farm mussel spat by *Notolabrus celidotus*

Predation of mussel spat (newly-settled mussels) by fish is a serious problem in the green-shell mussel industry of the Marlborough Sounds. Recently-seeded spat are reportedly most vulnerable. Entire lines can be stripped (Meredyth-Young, 1985a; pers. comm. Hayden, 1992), requiring the considerable labour and expense of reseeded or replacing these lines. *Notolabrus celidotus*, *Parika scaber* and *Chrysophrys auratus* are the three fishes reportedly responsible (Meredyth-Young, 1985a). However, adult *N. celidotus* have the greatest effect since they are very abundant in the Marlborough Sounds; most reports of ongoing predation are attributed to this species (Meredyth-Young, 1985a; MAFFisheries Nelson, 1990).

Mussel farms in water less than 15 m deep seem to act as an artificial reef, resulting in the build up of large populations of *N. celidotus* (Meredyth-Young, 1985a). To date, many different techniques have been used to remove problem fish, particularly *N. celidotus*, from mussel farms. Fish-scaring devices have been tried with only limited short-term success (pers. comm. Meredyth-Young, 1992), and intensive potting can only reduce *N. celidotus* populations in small, localised areas (Meredyth-Young, 1985a). The only relief from the problem of fish predation so far has been to manage the mussel crop in ways that minimise losses (Meredyth-Young, 1985a).

To further compound difficulties, the effects of predation are variable from place to place and time to time. Therefore, in formulating any response to the fish predation problem, several questions must be addressed relating to the dispersal and population biology of *N. celidotus* resident on and around mussel farms.

These are:

1. When and from where do the populations of *N. celidotus* that destroy mussels originate?
2. Does *N. celidotus* recruit directly into structures of mussel farms, or into nearby natural reefs and then to farms?
3. Is the local distribution of *N. celidotus* influenced by features of the mussel farm? If so, do these influences change as the fish grow?

In order to determine the source of *N. celidotus* affecting mussel lines, it is necessary to understand abundance patterns, reproduction, growth and recruitment patterns. Some information is available from northern New Zealand (Choat, 1965; Todd 1969; Jones 1980, 1981a, 1981b, 1984a, 1984b, 1984c; Choat and Ayling, 1987), but it is unlikely that the same patterns exist in the Marlborough Sounds.

### **1.1.2 Background review of the labrid *Notolabrus celidotus***

Wrasses (Labridae) are a large family of reef fish that have undergone intensive study in both tropical and temperate areas (Bray and Ebeling, 1975). In New Zealand, wrasses are represented by more species than any other group of reef fish (Ayling, 1987). They are equipped with large, pointed canine teeth set at the front of each jaw, and they prey on a variety of invertebrate species from the benthos and from seaweed fronds (Ayling, 1987). Many species also act as cleaners by removing ectoparasites and dead skin from larger reef fish (Thompson and Jones, 1983; Ayling, 1987), although this behaviour is more opportunistic than specialised (Bray and Ebeling, 1975; Thompson and Jones, 1983). Wrasses are mostly diurnal, being active in the day-time and seeking out cover in holes, burying or protecting themselves with mucus envelopes and becoming dormant for the night (Bray and Ebeling, 1975). All of the New Zealand wrasses are protogynous hermaphrodites, starting out life as females (initial phase), going through a transitional phase and eventually ending up as males (terminal phase) (Ayling, 1987); generally all

juvenile fishes are female. As a family, they are more common in New Zealand's North Island (Ayling, 1987).

The labrid *Notolabrus celidotus* (formerly *Pseudolabrus celidotus*, revised by Russell, 1988) reaches a maximum length of about 260 mm SL (standard length) as an adult male and is common in coastal, harbour and estuarine waters less than 30 m deep throughout New Zealand (Ayling, 1987). *N. celidotus* was the first New Zealand wrasse to undergo intensive study (Choat, 1965; Todd, 1969; Jones, 1981a), and consequently, much is known of its life history (Jones, 1980), ecology (Thompson and Jones, 1983; Jones, 1984b; Jones, 1984c) and behaviour (Jones, 1981b; Jones, 1983; Jones, 1984a). Most of this research has centred in north-eastern New Zealand, where *N. celidotus* is a familiar fish inhabiting shallow, rocky reefs (Choat and Ayling, 1987).

*N. celidotus* spawn between late July and the end of November (Jones, 1980; Thompson and Jones, 1985), and the pelagic eggs accumulate at or near the surface between August and December (Robertson, 1973). After about two months, larvae eventually recruit to macro-algal strands in shallow water, such as the common kelp *Ecklonia radiata* (Jones, 1984; Ayling, 1987). Here they remain closely associated in the shelter of macro-algae for the first year of life, rapidly reaching 80 to 100 mm SL (Jones, 1983). Small fish (<50 mm SL) feed in small groups, mainly on gammarid amphipods and copepods which they remove from the frond surfaces of macro-algae (Jones, 1983). Hence, macro-algae plays an important role in determining the distribution of newly-settled *N. celidotus*, as they require it as a source of both food and shelter (Jones, 1984a; Jones, 1984b). Macro-algae tends to be located in patches throughout the habitat and, hence, so do groups of small juvenile *N. celidotus*, similar to wrasses studied in the kelp forests off Santa Barbara, California (Bray and Ebeling, 1975).

As *N. celidotus* increase in size, shelter dependence decreases (Jones, 1983). Growing juveniles become less clumped and more randomly dispersed; they also switch to feeding on amphipods and isopods, which they take from rock strata (Jones, 1983). Adult fish (>110 mm) are found in deeper water, where they feed mainly on crabs, ophiuroids, bivalves, gastropods and hermit crabs (Jones, 1983).

### 1.1.3 Historical patterns of reef fish abundance and distribution

A fundamental element of marine ecology is the description of patterns that characterise populations. These descriptive patterns lead to the formulation of hypotheses and experimental work that attempts to identify and explain the underlying ecological mechanisms involved in the establishment of observed patterns.

Studies that have observed reef fish numbers over space and time have consistently found that habitat structure has a significant influence on the distribution and abundance patterns of these fish (Bray and Ebeling, 1975; Russell, 1977; Leum and Choat, 1980; Kingett and Choat, 1981; Jones, 1984a; Jones, 1984b; Jones, 1984c; Choat and Ayling, 1987; McCormick and Choat, 1987; Choat *et al.*, 1988; Jones, 1988). Many studies have also implied that the influence of habitat on the distribution and abundance of reef fish is due to specific features that habitats provide (Bray and Ebeling, 1975; Russell, 1975; Russell, 1977; Jones, 1984a, 1984b; Choat and Ayling, 1987; Connell and Jones, 1992).

Several studies have observed correlations between topographic complexity (the amount of vertical relief) and the diversity of reef fish assemblages (listed in Jones, 1988), suggesting that reef fish respond to the physical nature of the substratum that a habitat provides (Connell, 1991). Other habitat characteristics, such as current speed, turf algal-cover and sessile invertebrate-cover, are also correlated with reef fish abundance (listed in Jones, 1988); however, densities of juvenile *N. celidotus* are notably tied to macro-algal cover (Jones, 1984b, 1988). The surfaces of macro-algae are inhabited by dense and diverse populations of motile organisms, including isopods, amphipods, polychaetes and copepods, that make up a major part of the diet for juveniles of many reef fish species (Jones, 1988). Macro-algae, therefore, plays an important role in shaping the abundance patterns of newly-settled reef fish, since it provides both food and shelter (Jones, 1984a; Jones, 1984b). The motile epifauna act as a trophic link between macro-algal primary production and the fish fauna, which, in temperate reef communities, is dominated by predators rather than herbivores (Choat & Ayling, 1987).



Reef fish numbers have also been observed to vary consistently within as well as between habitats (Jones, 1981a; Jones, 1984c; Choat and Ayling, 1987; Choat *et al*, 1988), reflecting the variety of other physical and biological influences involved in shaping the abundance and distribution of these animals (Ebeling *et al*, 1980).

Reef fishes typically produce large numbers of larval offspring that are dispersed into the pelagic environment. These offspring are produced by adults that are relatively sedentary (Sale, 1978), so the pelagic phase acts as a means of dispersal (Sale, 1980). The eggs and larvae from many small reef fish assemblages mix in the pelagic environment, and recruits arriving into an area are unlikely to be related to the resident adults (Ehrlich, 1975; Barlow, 1981).

The abundance of settling fish presumably "reflects the distribution and abundance of mature larval fishes in the surrounding waters" (Doherty, 1983). Hence, the number of recruits in an area is the result of processes of the pelagic environment that shaped the distribution of the larval phase (Doherty, 1983; Victor, 1983, 1986; Cowen, 1985; Doherty and Williams, 1988). On the other hand, the spatial variation of new recruits is determined by attributes that various habitats offer (Jones, 1984b; Choat *et al*, 1985; Bodkin, 1988; Carr, 1989; Connell and Jones, 1991). This is thought to be either the result of active habitat selection by settling fish (Choat *et al*, 1988) or abrupt episodes of mortality of those settling in unsuitable habitats (Connell and Jones, 1991).

It is the current view that variations in the structure of reef fish assemblages are primarily a consequence of earlier patterns of recruitment (Doherty, 1983; Victor, 1983, 1986; Sale, 1984; Cowen, 1985; Doherty and Williams, 1988). This view questions the importance of competition in determining the upper limits of reef fish populations (Jones, 1990) and is described by Doherty (1983) as the Non-equilibrium hypothesis. It predicts that pre-recruitment processes, such as plankton predation (Talbot, Russell and Anderson, 1978), and other oceanographic conditions (Choat *et al*, 1988) restrict the densities of settling fish to a level below that at which resources become limited by post-recruitment processes such as competition (Doherty, 1983). Hence the mechanisms responsible for the abundance and distribution of reef fish assemblages are independent of the number of conspecifics resident in an area.

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However, other workers believe that spatial patterns of abundance laid down at the settlement and recruitment stages are eroded during the reef phase of life by density-dependent post-recruitment processes (Stephens *et al*, 1970; Sale, 1976; Robertson, 1988). This more traditional equilibrium theory predicts that the size of each fish assemblage is maintained below the carrying capacity of its environment through biological processes, such as competition for limited food and shelter (Doherty, 1983).

Most workers have viewed these alternative models as mutually exclusive, but experimental density manipulations have been unable to clarify this point, since correlations between recruitment levels and population density over a period of years may (Doherty, 1983; Victor, 1983, 1986; Doherty and Williams, 1988) or may not (Stephens *et al*, 1970; Sale, 1976; Robertson, 1988) be observed. Populations of reef fish can be either equilibrial (excess recruitment, competition extreme) or nonequilibrial (variable recruitment, competition unimportant) (Connell and Jones, 1991).

Manipulation experiments of recruitment levels in the damselfish *Pomacentrus amboinensis* suggests that natural variation in recruitment success does affect the importance of post-recruitment processes such as competition (Jones, 1990). That is, in areas where recruitment success is always below the environment's carrying capacity, the abundance of adults will reflect previous variations in recruitment success (Jones, 1990). However, in areas with high levels of recruitment, adult densities are limited by density-dependent processes (Jones, 1990).

Clearly then, to identify ecological mechanisms determining the population dynamics of a reef fish species, it is necessary to sort out the relative importance of processes occurring during both the pelagic and reef-associated phases of the life cycle. Ideally, such a study should monitor the fate of successive cohorts moving temporally through the pelagic environment, settling in an appropriate habitat and surviving to breeding age (Jones, 1988). However, due to the time limitations imposed on an MSc thesis, this is not possible for an organism as long-lived as a reef fish. The alternative, therefore, is to focus on both the planktonic and reef-associated phases at the same time

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over a wide spatial scale and to then infer temporal variations based on the observed distributions of size classes. This is a realistic approach, since several studies have found that spatial variation in the abundance and distribution of reef fish (including rates of recruitment) are consistently greater than are temporal variation (Ebeling *et al*, 1980; Jones, 1984b; Jones, 1984c; Choat *et al*, 1988). Choat *et al* (1988) proposed that the mechanisms shaping spatial distribution are distinct from those shaping temporal distribution and that temporal variation does not override spatial patterns, but only enhances them.

#### 1.1.4 Structure of the study

The approach taken in this thesis was as follows:

**Chapter Two:** A spatially-stratified plankton survey was done in the Hikapu Reach and in both Kenepuru and Pelorus Sounds during November 1992. This was done to provide a preliminary assessment of the spatial patterns of planktonic stocks of *N. celidotus* in these areas so that their importance in determining the distributional abundance of newly-recruited fish could be examined.

**Chapter Three:** Visual strip-transects, undertaken using SCUBA, were used to estimate the abundance and structure of populations of juvenile *N. celidotus* in both mussel farms and neighbouring coastal natural subtidal areas. Areas in both Pelorus and Kenepuru Sounds were sampled seasonally, in a stratified manner, for two years. To determine at what time and in what areas of the environment *N. celidotus* recruit, size-frequency analyses were carried out on juvenile fish observed in both mussel farms and neighbouring coastal natural subtidal areas seasonally over a one-year period.

**Chapter Four:** Information was acquired about the social structure of adult *N. celidotus* living on mussel farms. Samples of gonad from thirty fish (>100mm SL) were taken for two years. These were taken bi-monthly in the first year and monthly in the second year. From these samples, age, size, gonad weight and sexual phase were determined through histological examination.

**Chapter Five:** A manipulative experiment was done to see what effect removing juvenile habitat from the structure of mussel farms has on the distribution and abundance of settling and developing *N. celidotus*.

## 1.2 STUDY AREA

### 1.2.1 Marlborough Sounds

The Marlborough Sounds are located in the extreme northeast of the South Island of New Zealand. The two major sounds, Pelorus and Queen Charlotte, were formed by coastal submergence (Cotton, 1960). The entire area extends from 40°55'S to 41°18'S and from 173°43'E to 174°23'E (Figure 1.1). Of the two major waterways, Pelorus Sound is the primary site for the cultivation of mussels in New Zealand.

Pelorus Sound is a drowned river valley system fed by two major rivers at its head (Cotton, 1960). It consists of the main sound (Pelorus), four major re-entrants and numerous small bays. It is about 1.5 km wide and 30 m deep at the head, approximately 50 km long, 2.4 km wide and 70 m deep at the mouth. It has an estimated surface area of 290 km<sup>2</sup> and a water residence time of 21 days (Heath, 1974). Kenepuru Sound is a large re-entrant in the southern reaches of Pelorus Sound. It is a major site of mussel cultivation and extends 22 km north-eastward of the junction of the Hikapu Reach and the Mahau Sound arm (Figure 1.1).

### 1.2.2 Specific Study Sites

Five specific coastal areas of the Kenepuru and Pelorus Sounds were selected as study sites for the different components of this thesis. These are listed below; however, the sites sampled in the plankton survey (Chapter Two) are not included here.

#### Kenepuru Sound

- a) Waitaria Bay (174°2.5'E by 41°4.5'S). Situated roughly in the centre of the Kenepuru Sound, this sheltered shallow area has stony beaches gently sloping to a barren and very silty seabed.

- b) Schnapper Point (173°56'E by 41°12.5'S). The Schnapper Point site is a sharply-sloping area of shoreline 2.5 km west of where Schnapper Point is located on Fig.1.1, near the mouth of Kenepuru Sound. The rocky shoreline is broken by sandy patches of beach. Sparse macro-algal-covered rock and sand extend down to about 6 m, where the seabed becomes silty. This area is subject to high rates of tidal flows.
- c) Skiddaw (173°54'E by 41°12'S). Located 3.5 km west of Schnapper Point on the north side of Kenepuru Sound, near the mouth. It is a shallow area with stony beaches gently sloping to a barren, silty seabed.

### **Pelorus Sound**

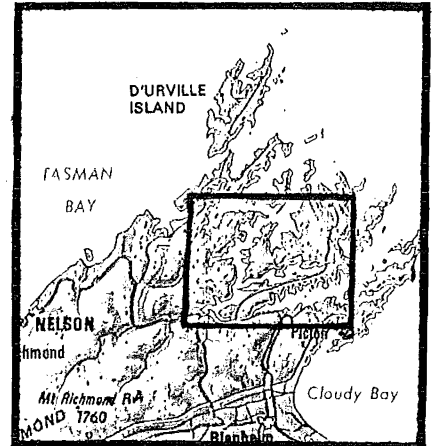
- d) Clova and Otatara Bays (174°2.4'E by 41°5.5'S and 174°2.5'E by 41°4.5'S). The sites used in these areas were only a short distance apart and hence were treated as one area. They are located at the northwest head of Clova Bay where the sandy seabed abruptly drops away from stony beaches and rocky macro-algal covered natural subtidal areas.
- e) Elie Bay (174°E by 41°7.5'S). Located in the centre of Crail Bay. Here the stony beaches and macro-algal covered rocky natural subtidal area gently slopes away to a shallow area of sandy seabed.

Figure 1.1: A) Location of the study area in New Zealand. B) A map of Marlborough. C) A map of the inner Pelorus and Kenepuru Sounds where study sites were located. Study sites labelled are: a) Waitaria Bay, b) Schnapper Point, c) Skiddaw, d) Clova and Otatara Bays, e) Elie Bay.

A) South Island of New Zealand.

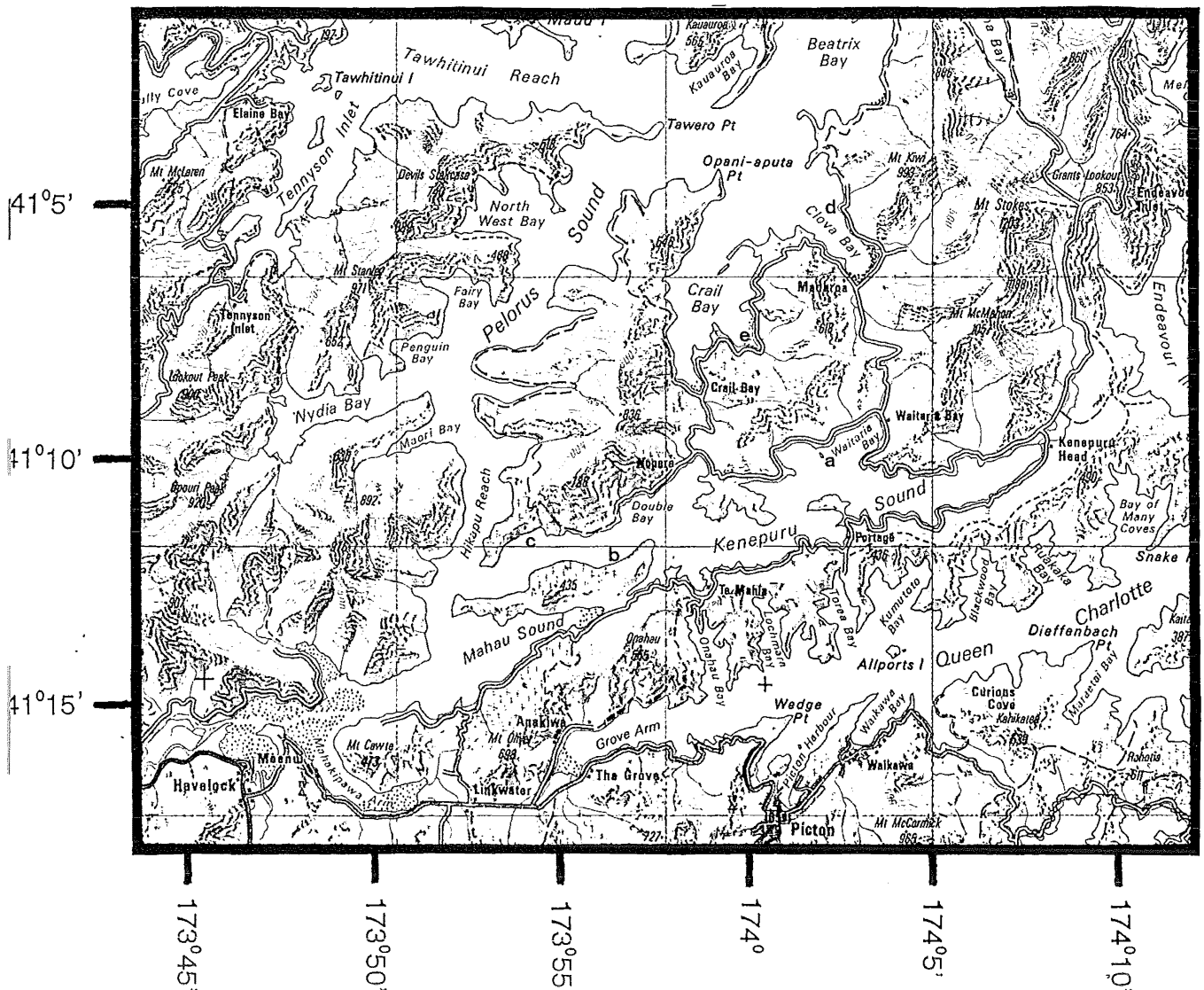


B) Marlborough Sounds location.



C) Study sites in the Pelorus and Kenepuru Sounds.

5 0 5 kilometres



## CHAPTER TWO

### PATTERNS OF PLANKTONIC EGG ABUNDANCE

#### 2.1 INTRODUCTION

Several studies of marine invertebrates with a planktonic dispersal phase have concluded that two locations can differ in the densities of new recruits simply because planktonic larvae were brought into one location at a higher rate than at the other (reviewed by Connell, 1985; Butman, 1987; Scandol and James, 1992). Such studies highlight the potential importance of population dynamics in the planktonic, settlement and recruitment periods.

Studies of reef fish have shown that the amount of ichthoplankton in an area is not simply a reflection of viable eggs produced by resident adults, as in terrestrial organisms (Sale, 1980; Connell, 1985; Butman, 1987). Instead, the distribution of ichthoplankton prior to settlement is determined primarily by a combination of factors in the pelagic environment (Barlow, 1981; Stephens and Zerba, 1981; Victor, 1983, 1986; Connell, 1985; Doherty, Williams and Sale, 1985; Kingsford and Choat, 1986; Kingsford, 1988; Kingsford *et al*, 1991).

Many of these studies have also shown that the effects of properties of the pelagic environment acting on the distribution of ichthoplankton can continue to be observed in the distributions of newly-recruited juvenile reef fish (Barlow, 1981; Stephens and Zerba, 1981; Doherty, Williams and Sale, 1985; Victor, 1983, 1986; Kingsford and Choat, 1986; Kingsford, 1988; Kingsford, Wolanski and Choat, 1991). In fact, for some temperate species the rate of settlement in an area can be predicted relatively accurately from the abundance of planktonic larvae (review by Sale *et al*, 1985). For example, large-scale spatial variations in recruitment levels of the temperate wrasse *Semicossyphus pulcher* are consistent with large-scale variations in ocean currents off the coast of California (Cowen, 1985). Several other possible effects of oceanographic features on the planktonic stages of reef organisms are outlined in Table 2.1.



**Table 2.1** Observed effects of oceanographic features on the early life history stages of reef-associated organisms. After Kingsford (1990).

Observed Oceanographic Effect	Reference
aggregation	Shanks and Wright (1987) Shenker (1988)
retention near reefs	Allredge and Hamner (1980) Lobel and Robinson (1986)
onshore movement	Kingsford and Choat (1986)
offshore movement	Pearce and Phillips (1988)
concentration of food	Lasker (1975)
interactions with other plankters	Purcell (1985)

A knowledge of the distribution and abundance of the planktonic phase is fundamental to understanding the distribution and abundance of a marine organism for two basic reasons. Firstly, it is the dispersal of the planktonic phase, not that of adults, which determines the regional limit of reef fish populations, and secondly, since most mortality takes place between spawning and settlement, events during the planktonic phase may also limit the size of adult populations (Sale *et al*, 1985). Adult *Notolabrus celidotus* broadcast their eggs into the water column when mating (Jones, 1981a). The eggs float to the surface and hatch after about 120 hrs (Robertson, 1973). Larvae then live pelagically for approximately another two months (Jones, 1980 and 1981a), during which time they are available to transport by currents and subject to the effects of the pelagic biota (Kingsford, 1990).

Several studies have highlighted the importance of local eddies in maintaining stock densities of island reef fish (references listed in Cowen, 1985), although few have had the opportunity to view ichthoplanktonic distribution and abundance patterns in terms of detailed observations of localised oceanographic events (Sale *et al*, 1985). Fortunately, many hydrological processes operating in the Pelorus Sound and in its Kenepuru arm have already been examined (Carter, 1976; Heath, 1974a, 1976, 1982; Bradford *et al*, 1987). To provide insight as to the importance of these processes in shaping distributions of planktonic and possibly juvenile *N. celidotus* (juvenile

observations outlined in Chapter Three), quantitative assessment of plankton stock were made in Hikapu Reach, Kenepuru Sound and mid-Pelorus Sound.

As this was a one-off investigation aimed only at describing the spatial distributions of planktonic *N. celidotus*, it did not incorporate a temporal component. Consequently, the timing of samples was crucial. Because spawning of adult *N. celidotus* resident in study areas appeared to occur mostly between October and December (Chapter Four), the current regime from October to January was thought to have the greatest effect on larval dispersal (Cowen, 1985). The survey was, therefore, done during the middle of this period, i.e. late November/early December.

Due partly to the timing of the survey (few larvae were found) and also because past studies have highlighted difficulties in identification (Robertson, 1973) and net avoidance (Kingsford and Tricklebank, 1991) associated with sampling teleost larvae, teleost eggs were targeted in this survey. However, the results may not be a representation of the true ichthyoplankton assemblages in the areas sampled, as the methodology and the timing of sampling were optimised to sample *N. celidotus* eggs (Robertson, 1973; Kingsford, 1988).

## 2.2 MATERIALS AND METHODS

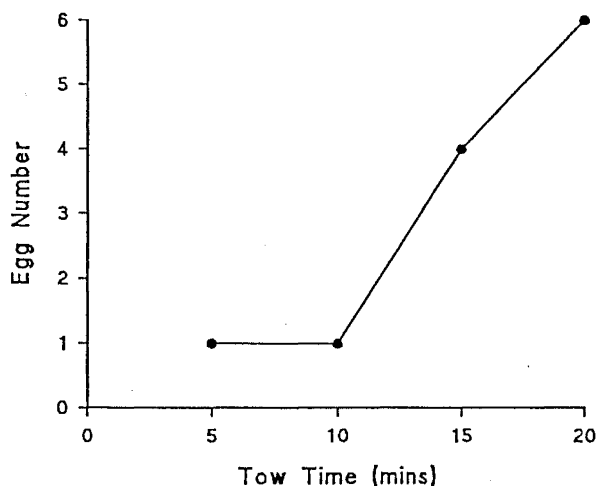
### 2.2.1 Collection materials and methods

Because teleost eggs tend to accumulate at or near the surface, plankton was collected using horizontal surface tows (Robertson, 1973). Samples were gathered using a net of 0.4 m mouth diameter and a total length of 2.5 m. Mesh size in the anterior 0.5 m was 10 mm and in the posterior 2 m was 0.1 mm. The net was equipped with both an internal and an external flowmeter. Tows were done at 2.5 knots ( $4.65 \text{ km/h}$ ) for 20 minutes. Collected material was preserved in a 5% formalin solution buffered with sea water.

### 2.2.2 Determining an optimal tow time

Four different tow times were tried to determine a tow duration that would yield egg numbers in sufficient yet manageable amounts. Tows of 5, 10, 15 and 20 minutes were each done once in the same area of Waitaria Bay (Kenepuru Sound) in early November 1992. The results showed that egg numbers were relative to the duration of tows, and that to catch meaningful sample sizes tows would need to be of the longest possible duration (Figure 2.1.).

**Figure 2.1:** Test tows to determine an optimal tow time based on the number of *Notolabrus celidotus* eggs captured.



### 2.2.3 Measurement of the water volume filtered

The flowmeters used in this study were calibrated prior to surveys (Omori and Ikeda, 1984). On a very calm day with no detectable current, a surface distance of 50 m was marked out with anchored buoys. The flow meters, mounted to the net mouth with the net removed, were towed horizontally at 2.5 knots along the marked distance (Tranter and Smith 1968). At the end of the tow the number of revolutions for each flowmeter was recorded. This was then repeated six times to yield a reliable mean number of revolutions equating to the distance of 50 m for each flowmeter. The calibration coefficient for each flowmeter was then determined by dividing the distance travelled (50 m) by the mean number of revolutions to determine the distance travelled in one revolution at 2.5 knots. At the conclusion of each plankton tow, the relative distance of water that had travelled through the net could be determined by multiplying the internal flowmeter's recorded number of revolutions by its calibration coefficient.

The purpose of having an external flowmeter was to determine the net's integrated filtration efficiency for each tow (Tranter and Smith 1968). This value is the ratio of the distance of water travelled through the net (internal flowmeter) to the distance that the net travelled through the water (external flowmeter) (Tranter and Smith 1968). It is a measure of a net's resistance to the water flow (Heron 1968) and hence, an indicator of mesh clogging (Tranter and Smith 1968). The UNESCO working group advises that a value of less than 85% signals clogging has occurred and that the tow should not be regarded as quantitatively accurate (Tranter and Smith 1968). This value was often reached when the net was towed through a swarm of the common jellyfish *Aurelia aurita*, thus necessitating repeating the tow.

For each tow, the total volume of water sampled ( $V$ ) by the net was determined using the formula  $V=ADF$ , where  $A$ =the mouth area,  $D$ =the distance towed and  $F$ =the integrated filtration efficiency (Omori and Ikeda 1984). The average volume of water sampled by the net towed at 2.5 knots for 20 minutes was  $264.1 \pm 5.5 \text{ m}^3$ . To compensate for variations in the volumes sampled, all tows were standardised to  $265 \text{ m}^3$  and the sample volume determined for each individual tow was expressed as a proportion of the standardised sample volume ( $265 \text{ m}^3$ ). The number of eggs counted

in each tow were then multiplied by this proportion to yield a standardised sample. Proportions ranged from 0.92 to 1.99.

#### 2.2.4 Sub-sampling

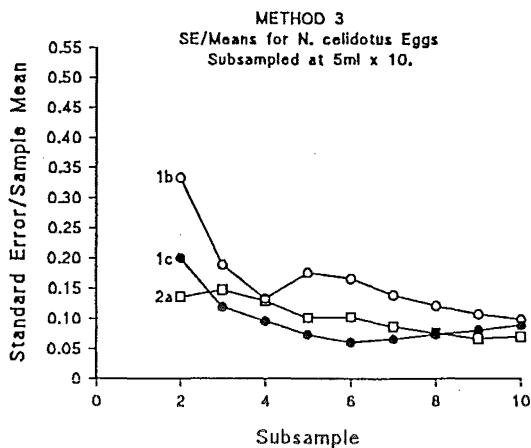
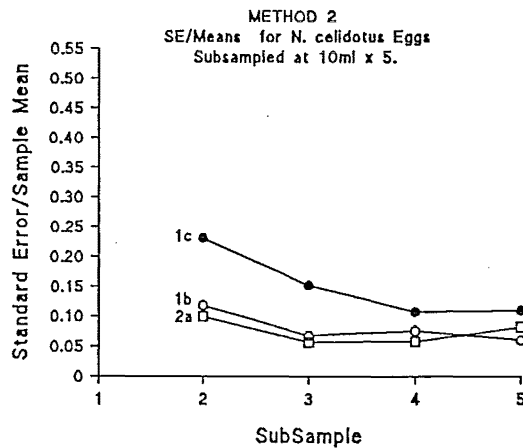
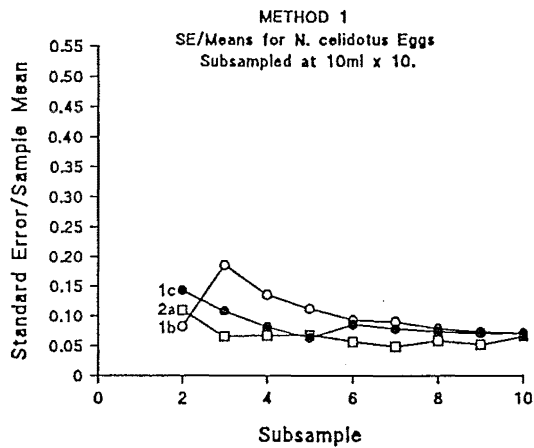
Sorting and identification of captured teleost eggs was time consuming because of the number of tows and the larger than expected number of eggs in some areas. Subsampling was done by first straining each sample through a 0.5 mm sieve to remove particles smaller than teleost eggs (Robertson, 1975). The sieved material was then made up to 100 ml with the preservative. The solution was mixed thoroughly by moving a swirling flask in a figure-8 track on a bench top for five seconds, this being an effective means of avoiding vortices that can cause an uneven distribution of the organisms in the flask (Edmonson and Winberg, 1971; McCallum, 1979). Subsamples were then taken with an automatic micro-pipette and sorted (Section 2.2.5).

The number of subsamples required was determined by subsampling to completion the plankton caught in three tows. This was done three times to assess three subsampling methods. The subsampling methods tested were:

- 1) The starting volume was set to 100 ml and 10 subsamples of 10 ml were taken.
- 2) The starting volume was set to 50 ml and 5 subsamples of 5 ml were taken.
- 3) The starting volume was set to 50 ml and 10 subsamples of 5 ml were taken.

No subsampling method took less time to complete counting all teleost eggs caught, but for *N. celidotus* eggs, it was possible to stabilise precision to within 10% of the true mean most rapidly using the first method (Figure 2.3). Using method one, six subsamples of 10 ml (60% of sample) were sufficient to ensure that the subsampled mean was precise to within <10% of the sample mean (Figure 2.3). The highest accuracy in subsampling was also observed after six subsamples were taken using method one. Consequently, all samples were strained and made up to a starting volume of 100 ml and six subsamples of 10 ml were taken and sorted.

Figure 2.2: The three subsampling methods tested for precision in estimating the true mean of plankton samples. The cumulative standard error is expressed as a proportion of the samples true mean. The actual number (true mean) of *Notolabrus celidotus* eggs in each tow was: Tow 1b=161; tow 1c=262; tow 2a=251.



### 2.2.5 Sorting and identification

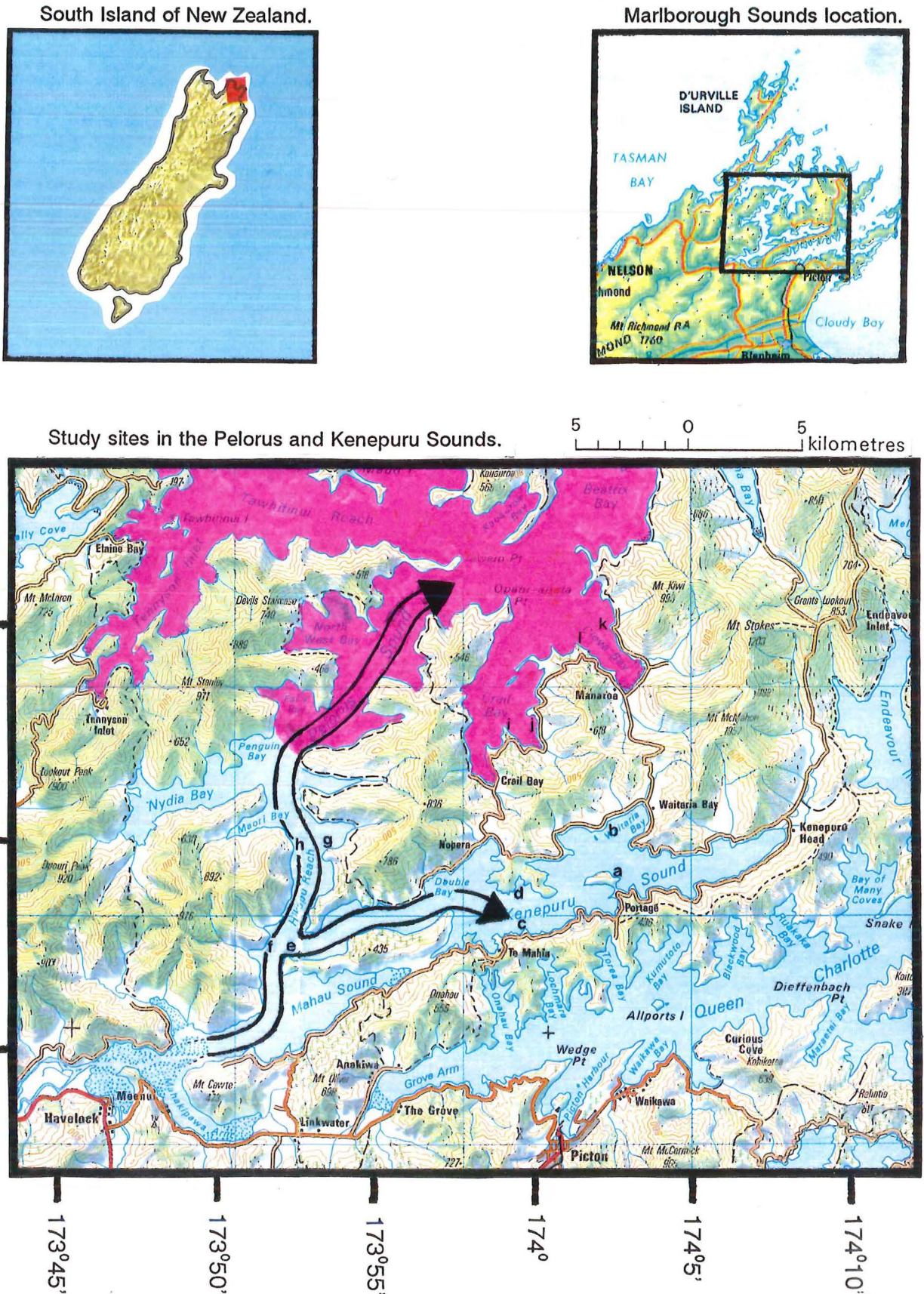
Each subsample was placed in a petri dish, further diluted and examined using a low-power binocular microscope to separate teleost eggs from the rest of the plankton. Eggs were then sorted into similar types, counted and identified, where possible.

Identification was achieved using methods outlined by Robertson (1973, 1975). A high-powered microscope was used to measure the diameters of the egg types. Oil droplets were also counted and measured if present. These observations and other noted features were then compared to Robertson's key (Robertson, 1975) in an attempt to find a match. To ensure identifications were correct, a sample of each egg type was sent to Dr D.A. Robertson at MAF Fisheries, Greta Point. His subsequent comments ensured that identifications were as accurate as possible.

### 2.2.6 Sample design

Four sites were sampled in Kenepuru Sound, Hikapu Reach and the Beatrix-Clova-Crail Bay complex of Pelorus Sound (Figure 2.3). Within each of these areas, sites were sampled in pairs approximately 1 km apart. In both the narrow Kenepuru Sound and Hikapu Reach, one site for each pair was sited near adjacent sides of the water mass (Figure 2.3). In the wider Beatrix-Clova-Crail Bay complex of Pelorus Sound, sites of each pair were positioned at the adjacent heads of Elie Bay (in Crail Bay) and Clova Bay (Figure 2.3). Each of the paired sites were spaced approximately 5 km apart and were centralised so as to be representative of the body of water sampled (Figure 2.3). Three replicate tows were done at each site.

**Figure 2.3:** Location of sampled sites used in the planktonic teleost egg survey. Three 20 minute surface tows were done at four sites in Kenepuru Sound (a,b,c,d), Hikapu Reach (e,f,g,h) and in the Crail-Clova Bay complex of mid-Pelorus Sound (i,j,k,l). The large black arrow depicts a seaward moving surface layer of low saline water (Heath, 1976, 1982; Carter, 1976; Bradford *et al*, 1987). The highlighted area shows a region of frequent high concentrations of the jellyfish *Aurelia aurita*.





## 2.3 RESULTS

Planktonic teleost eggs were most abundant in Kenepuru Sound regardless of species (Figure 2.4). Of all species encountered, *N. celidotus* eggs were consistently the most common, except for those sites in Hikapu Reach, where more *Chrysophrys auratus* (Snapper) eggs were captured (Figure 2.4).

Compared to other areas, sites in the Beatrix-Clova-Crail Bay complex of Pelorus Sound had the fewest eggs of all species except *N. celidotus* (Figure 2.4). The differences between the total abundance of eggs captured in each sound were significant for all species encountered (Table 2.2). The percentage of the proportioned variance accounted for by sounds was 67.2% for *Rhombosolea* species (Flounders), 60.8% for *N. celidotus* and 48.6% for *C. auratus* (Table 2.2).

There were also significant differences between sites within sounds for four out of five species (Table 2.2). Of these, the proportional variance accounted for by sites ranged from 15.6% to 34.7%, much less than differences between sounds (Table 2.2).

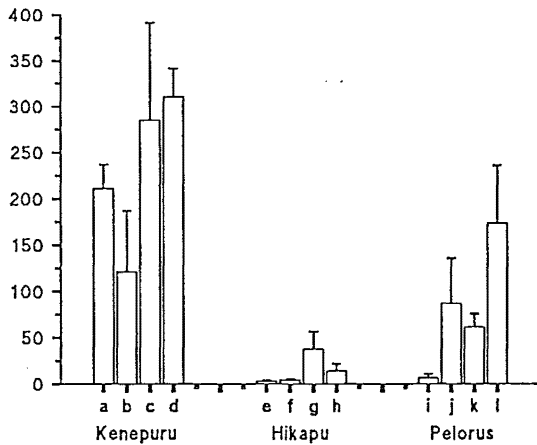
Because the sample for each tow was subsampled, a mean and variance was associated with each tow. For all species, replicate tows were significantly different in egg numbers (Table 2.2). A considerable source of variation also occurred at this level, with proportional variance ranging from 9.9% for *Rhombosolea* species to 32.5% for *S. neopilchardus* (Table 2.2).

The residual variation was surprising low for *N. celidotus* (5%), *C. auratus* (9.1%) and *Rhombosolea* species (7.4%) (Table 2.2).

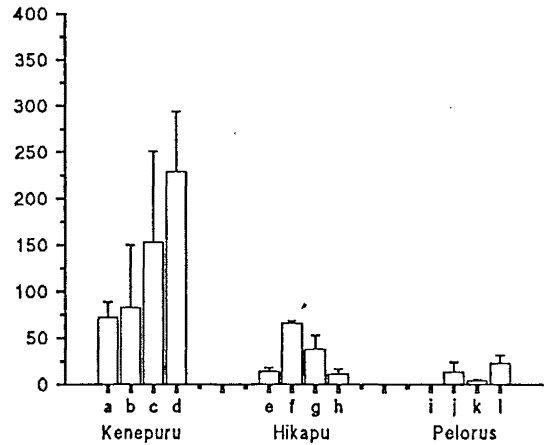
No *Parika scaber* (leather jacket) eggs were found; however, they were out of season (Kingsford, 1988).

Figure 2.4: Mean numbers of teleost eggs captured in surface tows (n=3) done at four sites in Kenepuru Sound (a,b,c,d), Hikapu Reach (e,f,g,h) and Pelorus Sound (i,j,k,l). In each sample area, sites were paired approximately 1 km apart and couplets sites spaced approximately 5 km apart. Locations of each site are shown in Figure 2.4.

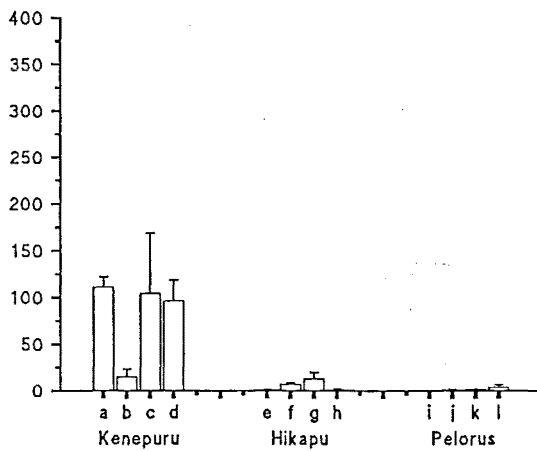
*Notolabrus celidodus*



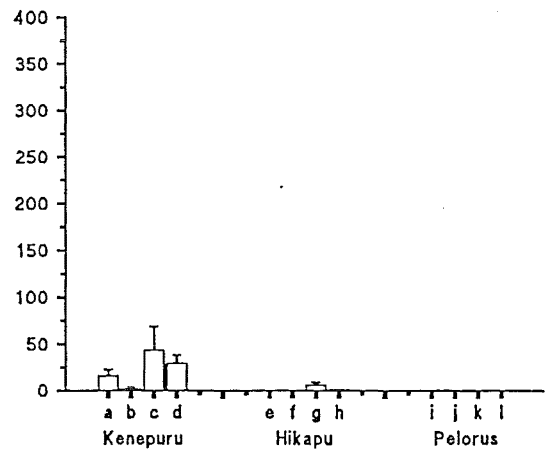
*Chrysophrys auratus*



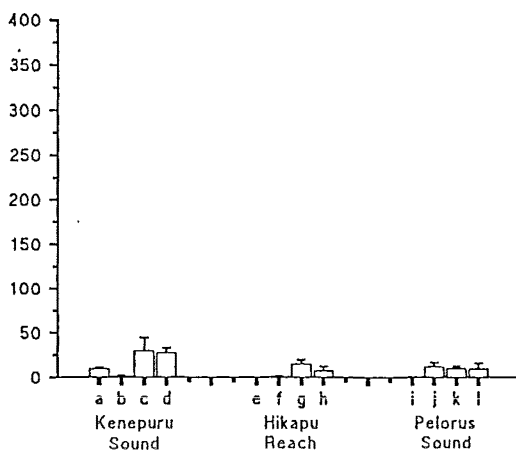
*Rhombosolea* spp.



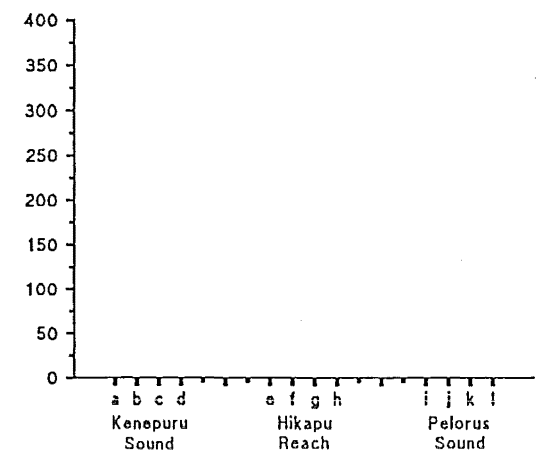
*Sardinops neopilchardus*



*Engraulis australis*



*Parika scaber*



Sample sites within survey areas

Table 2.2: ANOVAs for each species' planktonic egg densities captured in surface tows. Locations of tow sites are outlined in Figure 2.3. Cochran's tests were used to test homogeneity of variances. The percentages of the total variance accounted for by each factor are given; formula from Winer (1971). Sounds and sites were treated as fixed factors and tows were treated as a random factor.

Source	df	MS	F	P	%
A. Total densities of <u>Notolabrus celidotus</u> eggs <sup>1</sup>					
Sound	2	101.1844	56.60	<0.001	60.8
Site(Sound)	9	9.3298	5.22	0.001	22.2
Tow(Sound Site)	24	1.7881	15.54	<0.001	12.1
Residual	180	0.1150			5.0
Total	215				
B. Total densities of <u>Chrysophrys auratus</u> eggs <sup>2</sup>					
Sound	2	57.9656	24.73	<0.001	48.6
Site(Sound)	9	6.1313	2.62	0.029	20.1
Tow(Sound Site)	24	2.3448	15.58	<0.001	22.1
Residual	180	0.1505			9.1
Total	215				
C. Total densities of <u>Rhombosolea</u> species eggs <sup>3</sup>					
Sound	2	70.3247	72.91	<0.001	67.2
Site(Sound)	9	4.1711	4.32	0.002	15.6
Tow(Sound Site)	24	0.9645	9.04	<0.001	9.9
Residual	180	0.1067			7.4
Total	215				
D. Total densities of <u>Sardinops neopilchardus</u> eggs <sup>4</sup>					
Sound	2	117.753	10.45	0.001	30.4
Site(Sound)	9	19.827	1.75	ns	19.7
Tow(Sound Site)	24	11.321	12.16	<0.001	32.5
Residual	180	0.931			17.5
Total	215				
E. Total densities of <u>Engraulis australis</u> eggs <sup>5</sup>					
Sound	2	0.69506	5.82	0.009	11.0
Site(Sound)	9	0.55448	4.65	0.001	34.7
Tow(Sound Site)	24	0.11921	3.87	<0.001	17.6
Residual	180	0.03084			36.8
Total	215				

1. Data transformation  $\log-E(x+1)$ . Cochran's test  $C=0.1002$ , not significant (24 variances, 6 df).

2. Data transformation  $\log-E(x+1)$ . Cochran's test  $C=0.0840$ , not significant (24 variances, 6 df).

3. Data transformation  $\log-E(x+1)$ . Cochran's test  $C=0.1011$ , not significant (24 variances, 6 df).

4. ANOVA not reliable. Cochran's test  $C=15.2588$ ,  $p<0.001$  (24 variances, 6 df).

5. Data transformation  $\log-10(x+1)$ . Cochran's test  $C=0.1002$ , not significant (24 variances, 6 df).

## 2.4 DISCUSSION

Egg abundance for all species was quite variable and significant differences were observed at each spatial scale examined. However, most of the variation occurred at the largest scale, i.e., between the three survey areas (Kenepuru Sound, Hikapu Reach, Pelorus Sound) (Table 2.2). Past studies have found that the distribution of ichthoplankton at this spatial scale is primarily determined by processes occurring in common pelagic environments (Barlow, 1981; Stephens and Zerba, 1981; Victor, 1983, 1986; Connell, 1985; Doherty, Williams and Sale, 1985; Kingsford and Choat, 1986; Kingsford, 1988 and 1990; Kingsford, Wolanski and Choat, 1991).

Fortunately, many oceanographic processes operating in the Pelorus Sound and its Kenepuru arm have already been examined. They are reviewed here.

### 2.4.1 A review of oceanographic observations made in Pelorus and Kenepuru Sounds.

The Marlborough Sounds were formed by coastal submergence (Cotton, 1960). The Pelorus Sound is a drowned river valley system fed by two major rivers at its head (Cotton, 1960). It is approximately 50 km long and, including Kenepuru Sound, it has a surface area of 290 km<sup>2</sup> (Heath, 1974). Kenepuru Sound is a 22 km long side arm of Pelorus Sound with no substantial freshwater inflow (Heath, 1982). Direct current measurements within these areas have shown that the main flow of water is tidal (Heath; 1974 and 1976) with a residence time of about 21 days (Heath, 1974). However, Carter (1976) defines Pelorus Sound as a moderately stratified estuary due to a distinct low-salinity surface layer where the Pelorus and Kaituna Rivers flow into Pelorus Sound at its head. This river-influenced surface layer becomes progressively more saline as it travels seawards until, at the mouth of Pelorus Sound it is essentially of the same salinity as the water in Cook Strait (Heath, 1974 and 1976; Carter, 1976). As an estuarine circulatory system, the seaward moving, low-salinity surface layer is accompanied by a tidally-influenced level of no net motion at the mid-depth range, and a residual upstream counter-current movement of saline water at the bottom (Carter,

1976; Norcross and Shaw, 1984). This situation allows for the possible passive, upstream transport of planktonic organisms that migrate vertically to the lower, landward moving layers of water (rheotaxis) (Norcross and Shaw, 1984).

Rates of flow for the estuarine circulation system are generally very small compared with the tidal flow that dominates (Heath, 1974 and 1976). However, the estuarine circulation gains impetus with increasing freshwater inflow. During and after 125 mm of rainfall, Carter (1976) determined that the low-salinity surface layer (<2 m thick) moved rapidly seawards unaffected by tidal flow at speeds of 65-90 cm/s<sup>-1</sup>. This surface layer, distinguished by its turbidity, has been observed to extend from the Pelorus and Kaituna River mouths to just south of the entrance to the Beatrix-Clova-Craill Bay complex (Carter, 1976; Heath, 1976) (See Fig. 3.4). Based on these observations, Carter (1976) concluded that with intense freshwater inflow, seston (suspended sediment) was rapidly transported seaward in the low-salinity surface layer.

Bradford *et al* (1987) also tracked a 5-10 m thick surface layer of low-salinity water flowing seaward along the same route that Carter (1976) and Heath (1976) had previously observed. However, they also tracked it well into Kenepuru Sound (Bradford *et al*, 1987). They noted that during periods of high freshwater inflow, the resulting rapid movement of seaward-flowing surface water had a direct effect on the distribution of phytoplanktonic biomass (Bradford *et al*, 1987).

The distribution of particles restricted to the top 10 m of water in the inner Pelorus Sound and outer Kenepuru Sound will, therefore, be affected by this estuarine circulation system, depending on the level of recent rainfall in the area (Carter, 1976).

As well as the hydrological processes operating in the pelagic environment, biologically-controlled oceanographic events can also influence the distribution of suspended organisms (Lasker, 1975; Purcell, 1985; Kingsford, 1988). Bradford *et al* (1987) speculated that an absence of copepods in the zooplankton of mid-Pelorus Sound was due to predation by the jellyfish *Aurelia aurita*, which is conspicuously abundant in the area (Figure 2.3). They proposed that this leads to an accumulation of phytoplankton due to a reduction in grazing pressure from copepods (Bradford *et al*, 1987).

### 2.4.2 Hydrology and fish egg distribution.

Given sufficient rainfall, the estuarine water circulation system of Pelorus Sound can influence the distribution of both seston (Carter, 1976) and phytoplankton (Bradford *et al*, 1987). In fact, any passively buoyant particle appears to be affected by a surface layer of water, 10 m thick, moving at speeds of up to  $90 \text{ cm/s}^{-1}$  (Carter, 1976).

Based on the results of the survey reported here, it appears that the seaward moving low-salinity surface layer may influence the distribution of fish eggs by flushing them from its path in the Hikapu Reach, and by concentrating them at its ebb in Kenepuru Sound (Figure 2.4). Clearly, there were more fish eggs in the Kenepuru Sound than in any other area investigated (Figure 2.4). With a very long residence time, eggs flushed into this area after a heavy rainfall could remain concentrated there for up to 21 days (Heath, 1974). The Hikapu Reach, which lies mid-stream of this rapid surface flow, seems to be flushed clean of plankton during periods of heavy rainfall (Figure 2.3). However, in the interim between such events, the underlying tidal flow would produce a gradual movement of concentrated buoyant particles out of Kenepuru Sound (Bardford *et al*, 1987). This may explain the small number of fish eggs found in the Hikapu Reach (Figure 2.4).

None of the eggs captured in these areas, except perhaps *E. australis*, show any evidence of rheotopism (i.e., movement adjacent to the surface layer through vertical migration into other layers), as their distributions seem to be entirely consistent with surface currents. However, there does remain the possibility that egg densities were greater in the unsampled lower layers of water (Norcross and Shaw, 1984), but this would be inconsistent with previous findings (Robertson, 1973; Kingsford, 1988).

The area of Pelorus Sound where the estuarine flow of surface water, as measured by salinity, becomes too dissipated for detection is just south of the entrance to the Beatrix-Clova-Crail Bay complex (Heath, 1976 and 1982; Carter, 1976). However, sites sampled in both Crail and Clova Bays had relatively few fish eggs, except for those of *N. celidotus* (Figure 2.4). It is possible that the surface flow of water, although quite saline, continues on its course and travels around Tawero Point, past Maud Island, through the Waitata Reach (off the map) and out to sea (See Figure. 2.3). This

hypothesis is supported by a two-year survey of Pelorus Sound (Bradford *et al*, 1987) in which the greatest near-surface concentrations of chlorophyll *a* were consistently found at stations beyond Tawero Point (Figure 2.3). Since all organisms that produce oxygen during photosynthesis use chlorophyll *a* (Raven, Evert and Curtis, 1982), it is a good indicator of phytoplankton abundance. If phytoplankton is concentrated seaward of Tawero Point, so too could be fish eggs.

### **2.4.3 Effects of biological processes.**

Biological effects could also account for the relatively low numbers of fish eggs found in sites at Crail and Clova Bay. Bradford *et al* (1987) suggest that the virtual absence of copepods near Tawero Point is due to predation by the jellyfish *Aurelia aurita*, conspicuously abundant in the area (Figure 2.3). *A. aurita* is a suspension feeder that traps plankton in mucus on its flagellated subumbrellar surface (Barnes, 1987), taking particles <5 mm in diameter (Southward, 1955). The plankton net used in this survey often became clogged with these jellyfish at sites within the Beatrix-Clova-Crail Bay complex. Anecdotal information from long-time local residents affirmed that *A. aurita* regularly forms dense swarms in Crail Bay (pers. comm. Clark, 1993) and in Clova Bay (pers. comm. Harvey, 1993), where fish eggs were sparse (Figure 2.4). In Kenepuru Sound, where eggs were much more abundant, densities of *A. aurita* remained much lower than in Pelorus Sound (pers. comm. Godsiff, 1993 and Richards, 1993). Pelagic cnidarians are known to be important predators of fish eggs and larvae (Purcell, 1985), and this may have had the effect of reducing the abundance of fish eggs captured in the Beatrix-Clova-Crail Bay complex of Pelorus Sound.

### **2.4.4 Conclusion**

Based on the results of this survey and characteristics of the local pelagic environment, it appears that oceanographic features of Kenepuru and Pelorus Sounds do play some role in determining the spatial and abundance patterns of *N. celidotus* eggs, as well as those of most other species captured.

Localised oceanographic features probably also affect the settlement patterns of reef fishes (Kingsford, 1990; Kingsford *et al*, 1991). Settlement and subsequent recruitment are critical phases in the life history of reef fishes since the current view in the literature is that variations in reef fish densities are primarily a consequence of the number of recruits arriving in an area (Doherty, 1983; Victor, 1983 and 1986; Sale, 1984; Doherty and Williams, 1988). Therefore, spatial trends in the distribution of the planktonic phases, laid down in the pelagic environment prior to settlement, should also exist among newly-recruited juveniles.

It is well recognised that among reef fish populations considerable variations exist in rates of settlement and subsequent recruitment between years; however, considerable variation also exists on a variety of spatial scales (Kingsford, 1990). In a study of patterns of recruitment in the labrid *Semicossyphus pulcher*, Cowen (1985) found not only that large-scale variations in recruitment were consistent with variations in current flow, but also, in areas central to the ultimate source of larvae (i.e., where the spawning occurs) year-to-year variability did not greatly change the overall supply of larvae to large areas. On a smaller spatial scale, Jones (1984b) found that recruitment of *Notolabrus celidotus* at Leigh was also consistently more variable across space than between years.

Consequently, although making the assumption that *N. celidotus* egg numbers and recruitment levels in each area are relatively consistent between years<sup>1</sup>, the densities of eggs were compared to the number of newly-recruited *N. celidotus* observed in the same year (Chapter Three). The ratio of mean *N. celidotus* eggs captured in tows in Kenepuru and Pelorus Sounds were compared with the ratio of mean recruited *N. celidotus* (<20 mm SL) observed in Kenepuru and Pelorus Sound (Figure 2.5).

The ratio of mean *N. celidotus* eggs captured in Kenepuru Sound to those captured in Pelorus Sound was 2.77:1 (Figure 2.5). The ratio, between Sounds, for newly-recruited *N. celidotus* observed seasonally both in mussel farms and adjacent subtidal areas directly inshore was a relatively close 1.88:1 (Figure 2.5). It appears that

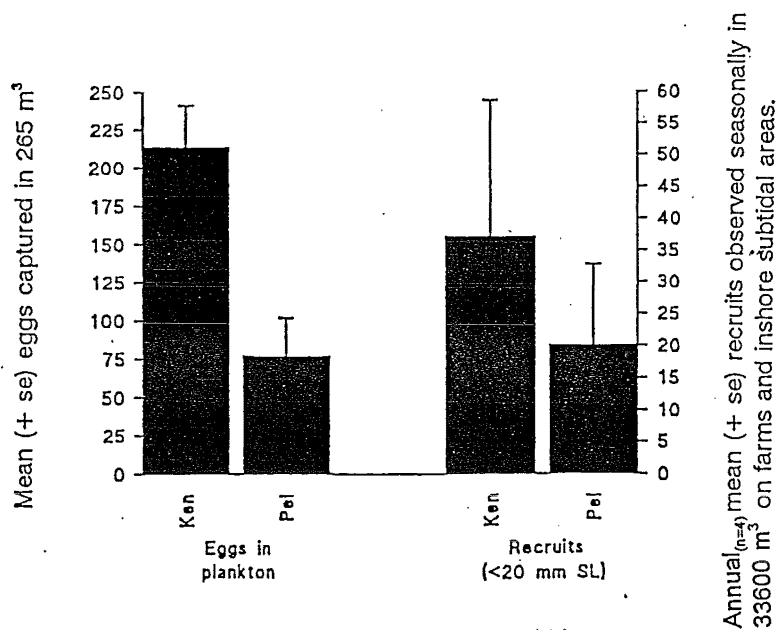
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<sup>1</sup> Jones' (1981a) finding of consistent yearly recruitment of North Island *N. celidotus* populations lends support to this assumption.



the number of recruits was higher in Kenepuru Sound where planktonic eggs may be concentrated by the estuarine water flow (Figure 2.5).

Figure 2.5: From subsamples, the mean number of *N. celidotus* eggs captured is shown for each of the 24 surface tows done in both the Kenepuru and Pelorus Sounds. Compared against these are total numbers of newly-recruited *N. celidotus* (<20 mm SL), averaged over seasons for two mussel farms and adjacent inshore subtidal areas within both Kenepuru and Pelorus Sounds (data from Chapter Three). Ken=Kenepuru Sound, Pel=Pelorus Sound.



Although the sample size is very small ( $n=2$ ), figure 6.5 does suggest that there is a relationship between the distribution of *N. celidotus* eggs and levels of new recruits. Within the obvious temporal limitations of this study, levels of settlement and subsequent recruitment in both Kenepuru and Pelorus Sounds appear to be a reflection of the number of eggs in the associated pelagic environment (Figure 2.5). Consequently, the number of fish settling an area may also be affected or determined by oceanographic processes operating in the pelagic environment.

The spatial distribution and abundance of *N. celidotus* recruits appear to reflect the distribution and abundance of eggs in the surrounding waters. This suggests that pre-recruitment processes operating in the pelagic environment may be able to influence densities of settling fish. However, it remains to be seen if the abundance and distribution patterns of newly-recruited *N. celidotus* in each area are then reflected in the abundance and distribution patterns of mature fish, as described by Doherty (1983) in the Non-equilibrium hypothesis.

In summary, it appears that estuarine water currents, produced by levels of high rainfall, and possibly planktonic predators play some ecological role by influencing the distribution and abundance of *N. celidotus* eggs. Surface currents provide a transport mechanism that concentrates planktonic eggs in specific areas, apparently also affecting the levels of juvenile settlement and subsequent recruitment. The magnitude of successive yearly recruitment in different areas may depend on how hard it rains each year.

The influence of oceanographic processes on subsequent year-classes following recruitment is generally uncertain for reef fish (Sale *et al*, 1985). Variations in the successive levels of settlement can play a primary role in determining localised stock dynamics, provided that the rate of settlement is not sufficient to saturate local resources (Doherty, 1983; Sale *et al*, 1985; Jones, 1990). Doherty's (1983) Non-equilibrium hypothesis predicts that settlement densities will always remain below the level at which resources become limiting, thwarting the need for resource-based theories of population regulation. This hypothesis will be further investigated in Chapter Three.

**CHAPTER THREE**  
**SPATIAL AND TEMPORAL VARIATIONS IN THE ABUNDANCE PATTERNS**  
**OF JUVENILE *NOTOLABRUS CELIDOTUS* AROUND MUSSEL FARMS**

**3.1 INTRODUCTION**

A characteristic of many marine populations is that recruitment can be quantitatively independent of the resident adults in that population. This basic difference between marine organisms and their terrestrial counterparts is the result of a planktonic dispersal phase early in marine life histories. The previous chapter indicated that at the egg phase, less than 120 hours after fertilization (Robertson, 1973), the distribution and abundances of *Notolabrus celidotus* appeared to be determined by hydrological and possibly biological processes operating in the pelagic environment. Such results have lead many ecologists to suggest that spatial and temporal changes in the distribution of reef fish are primarily a consequence of patterns laid down during the settlement and subsequent recruitment of juveniles from the plankton (Barlow, 1981; Stephens and Zerba, 1981; Victor, 1983, 1986; Cowen, 1985; Doherty, Williams and Sale, 1985; Kingsford and Choat, 1986; Kingsford, 1988; Kingsford, Wolanski and Choat, 1991). This view questions the traditional importance placed on post-recruitment processes such as competition in determining the upper size limits of reef fish populations (Jones, 1990). It is described by Doherty (1983) as the Non-equilibrium hypothesis and predicts that post-recruitment resource limitations do not affect the structure of reef fish populations because settlers arriving into an area will usually be less than the carrying capacity of the environment. However, other workers believe that spatial patterns of abundance laid down at the stages of settlement and recruitment are eroded during the reef phase of life by density-dependent, post-recruitment processes (Stephens *et al*, 1970; Sale, 1976; Shulman and Ogden, 1987; Robertson, 1988). To what degree patterns of reef fish distribution and abundance are determined by pre-recruitment and post-recruitment processes still remains a topic of some debate.

Several studies of *N. celidotus* have already been done in the North Island (Choat, 1965; Todd, 1969), most notably by G.P. Jones at the University of Auckland Marine

Laboratory at Leigh (Jones, 1980, 1981a, 1981b, 1983, 1984a, 1984b, 1984c). Jones (1981a) observed a high degree of spatial variation in the densities of *N. celidotus* with patterns persisting over several years. He also noted that densities of adult *N. celidotus* reflected those of juvenile recruitment (1984c). Furthermore, in an adult removal experiment Jones (1984b) showed that recruitment was independent of adult numbers. From these results, Jones (1984c) concluded that the positive relationship observed between juvenile and adult densities of *N. celidotus* were the result of patterns laid down at settlement (Jones, 1984b). He also suggested that a build-up of adult *N. celidotus* in an area was due to consistently high recruitment in that area over a period of years (Jones, 1984b).

Studies that have observed reef fish numbers over space and time have established that habitat structure has a significant influence on the distribution and abundance patterns of these fish (Bray and Ebeling, 1975; Russell, 1977; Leum and Choat, 1980; Kingett and Choat, 1981; Jones, 1984a, 1984b, 1984c and 1988; Choat and Ayling, 1987; McCormick and Choat, 1987; Choat, Ayling and Schiel, 1988). Jones showed that the distribution of juvenile *N. celidotus*, like that of many other juvenile reef fish, is especially associated with macro-algae (Jones, 1984a and 1984b). It appears that macro-algae facilitates the recruitment of *N. celidotus* by providing food and shelter for small fish (Jones, 1984a and 1984b). Jones (1984b) also showed a depth effect associated with the recruitment of *N. celidotus*. The general pattern that emerges from Jones' studies is that *N. celidotus* juveniles recruit into the shelter of shallow macro-algal habitats, remain closely associated with them throughout the first year of life and then move into deeper, more open habitats as they mature (Jones, 1980, 1984a and 1984b).

The aim of this study is to make similar observations of juvenile *N. celidotus* (<120 mm SL) around mussel farms in the Marlborough Sounds (for details of fish > 120 mm SL see Clarke, 1993) in an attempt to answer the following questions:

- 1) Are there differences in the abundance patterns of juvenile *N. celidotus* between regional locations and between different habitats within those locations?
- 2) Do these abundance patterns vary over time?
- 3) At what time and into what areas of the mussel farm environment do *N. celidotus* recruit?

For specific details of *N. celidotus* > 120 mm observed in this survey, see Clarke (1993).

## 3.2 MATERIALS AND METHODS

### 3.2.1 Mussel farm construction

Mussel farms of the Marlborough Sounds use a suspended cultivation technique, using paired long lines supported by regularly spaced floats (Figure 3.1a). Suspended from the long lines are vertical ropes, called dropper lines, onto which green shell mussels (*Perna canaliculus*) are attached (Jenkins, 1985) (Figures 3.1b and c). Mussels grow by feeding on plankton.

There are two basic parts to this type of mussel farm structure. These are:

1. A series of floats roped together by a pair of long-lines (known as a mussel line or backbone), arranged in 3 to 10 rows approximately 110 m long and 17 m apart (Figure 3.1a). Mussel lines are usually arrayed parallel to shore. Pairs of dropper lines covered with attached mussels are suspended into the water column from the floating mussel lines (Meredyth-Young, 1985b) (Figure 3.1b).
2. Large concrete mooring blocks (2.5 or 3.5 tonnes) anchor the mussel lines by a bridle and a single mooring rope at each end (Meredyth-Young, 1985b) (Figures 3.1a and b). However, screw in anchors are also used occasionally to moor mussel lines.

### 3.2.2 Fish census

Most ecological studies, at some point, require an estimate of the number of individuals of a species present in an area. Methods for obtaining this information for reef fish communities are many. They can, however, be divided into destructive techniques that physically remove samples of fishes from an area in question, and non-destructive techniques of visual census by divers using SCUBA (Sale, 1980). The destructive techniques include selective methods such as angling, fish traps, spearing and other forms of fishing gear. The most destructive techniques involve the use of poisons (eg.

rotenone), anaesthetics (eg. quinaldine) and explosives (eg. tuna bombs and jelicnite); these can yield very accurate and unbiased estimates of the fish present in a defined area (Russel, Talbot, Anderson and Goldman, 1978). However, the non-destructive visual census techniques were chosen for this survey principally because they allow repeated sampling without physical disturbances of the populations under investigation. Although visual counting is an effective method for assessing reef fish densities, they do have an inherent tendency to under-estimate fish numbers due to the diver's inability to see every individual present in one moment (Sale, 1980).

The use of strip transects is one visual census method that has proven to be effective at estimating the diversity and abundance of reef fish communities (Russell, 1977; Leum and Choat, 1980; Sale and Douglas, 1981; Sale and Sharp, 1983; Jones, 1984c, 1984d; Thresher and Gunn, 1986). Brock (1954) was the first to use this technique for censuring reef fish populations. In his initial methods, two SCUBA divers swam on either side of a benthically-anchored line and recorded all of the fish in the water column above a transect of a prescribed width. The diver's counts were then combined to give the total number of fish observed within the area of the transect. In the present study, counts were made by swimming along transect lines and recording the presence, colour phase and standard length (Figure 4.1) of each fish observed within 2.5 m of either side of the transect line. This was similar to Brock's (1954) methods except that the transect line was not always anchored. Transects were also done around structures suspended in the water column (i.e., mussel dropper lines and anchor ropes). Both mussel farms and adjacent natural areas were visually sampled using this technique.

The colour phases of *N. celidotus* have been previously described (Choat, 1965) and the three phases distinguished in this study (initial, transitional and terminal phases) were the same as those used by Jones (1981a). Within the context of this thesis, however, only juvenile *N. celidotus* were examined in detail. Information about the spatial and temporal abundance patterns of adult female initial phase, transitional phase and terminal phase male fish recorded in these samples is available in Clarke (1993). Length estimates were visually made to the nearest 5 mm and were considered accurate

to within 5% of the actual length, since earlier practice at estimating the standard lengths of plastic cut-out fish placed in a natural environment had instilled a high level of accuracy in the divers. This accuracy was reinforced by comparing visual size and colour-phase estimates with sampled fish that had been measured and sexed (Chapter Five).

To avoid underestimating fish numbers due to poor visibility (particularly in the silty waters of the Kenepuru Sound) all counts were done only when visibility was greater than 2.5 m.

As labrids are diurnal (Bray and Ebeling, 1975, Ayling, 1987) and observations of juvenile *N. celidotus* replicated within days showed no significant change in spatial distributions throughout daylight hours (Section 3.2.3), counts were performed between 0900 and 1600hrs.

The effectiveness of underwater strip transects for determining the natural abundance of fish can be altered by the effects of divers on fish behaviour. Jones (1981a) reported that *N. celidotus* were seldom diver-negative but became diver-positive only when the benthos was disrupted. This is because fish forage opportunistically in the wake of benthic disturbances (Bray and Ebeling, 1975). Therefore, to ensure that diver influence on the natural fish distribution was minimal, all efforts were made by divers not to disrupt the benthos. As a result, no diver-positive behaviour was observed and fish were not seen to follow divers between transects.



### 3.2.3 Preliminary survey of mussel farms

Habitat variations such as bottom topography (Jones, 1984c) and macro-algal cover (Jones, 1984b, Choat and Ayling, 1987) are known to influence the abundance patterns of *N. celidotus*. Therefore, to focus our understanding of *N. celidotus* abundance patterns around mussel farms, a stratified sampling design was required to sample distinct areas of mussel farms. This approach seeks to identify and subsequently partition variation in fish densities that are inherent to the differences between habitats within each site (McCormick and Choat, 1987). Consequently, a pilot study was undertaken in Autumn 1991 to determine what, if any, habitat divisions relative to juvenile *N. celidotus* existed within mussel farms.

Based on preliminary observations of fish distributions around mussel farms, four parts of the mussel farm environment were considered to be of interest. They were:

1. The top 4 m of the mussel dropper lines,  
(Figure 3.1b-1 and Plate 3.1).
2. The bottom 4 m of the mussel dropper lines,  
(Figure 3.1b-2 and Plate 3.1).
3. The seabed directly below the suspended mussel dropper lines,  
(Figure 3.1b-3 and Plate 3.2).
4. The concrete mooring blocks,  
(Figure 3.1b-4 and Plate 3.3).

In this survey, sampled mussel farms were restricted to those in water 8-20 m deep as mussels in this depth are reportedly most prone to predation by *N. celidotus* (Meredyth-Young, 1985a; MAFFisheries Nelson, 1990). This had the effect of standardising the depths of sampled areas throughout replicated mussel farms. Within each sampled farm, the first five mussel lines were sampled (Figure 3.1a) using the following transects:

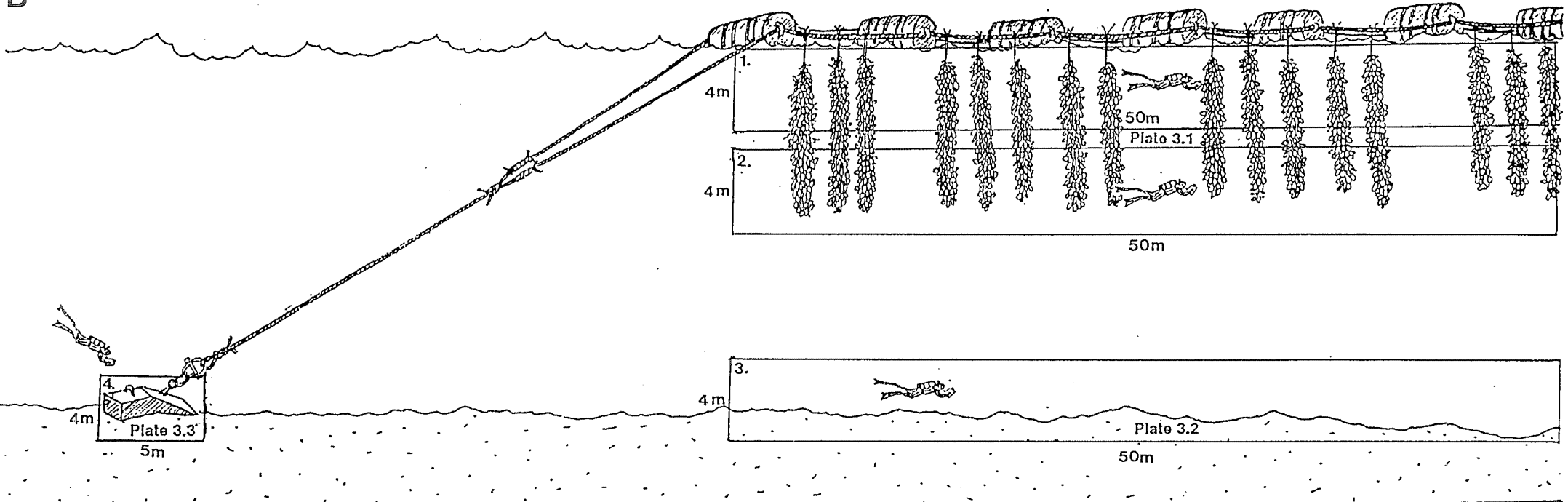
1. Along a randomly chosen segment of mussel line, a horizontal 50 m transect was done through the top 4 m of the vertical dropper lines (Figure 3.1b-1). Each diver would swim on one side of the dropper lines and record fish observed 2.5 m either side of an imaginary line between the paired dropper lines (Figure 3.1c-1). Counts from the two divers were then combined to give the abundance for the whole 5 m wide strip
2. Along the same segment of mussel line, a horizontal 50 m transect was then done through the bottom 4 m of the vertical dropper lines (Figure 3.1b-2). Each diver would swim on one side of the dropper lines and record fish observed 2.5 m either side of an imaginary line between the paired dropper lines (Figure 3.1c-2). Counts from the two divers were then combined to give the abundance for the whole 5 m wide strip.
3. A 50 m benthic transect was done on the seabed directly beneath the preceding transects (Fig 3.1b-3). One diver would swim below each row of suspended dropper lines and record fish observed above the seabed 2.5 m either side of an imaginary line between the paired dropper lines (Figure 3.1c-3). Counts from the two divers were then combined to give the abundance for the whole 5 m wide strip.
4. Divers would swim down one of the two mooring ropes (chosen at random) until they could see the mooring block. There they would hover above it and count the fish in a 5x5x4 m area around the mooring block (Figure 3.1b-4). The counts of each diver were then compared for accuracy, this was usually within 90%. This technique sampled only 100 m<sup>3</sup> whereas the others sampled 1000 m<sup>3</sup>.

This methodology required that the sampled mussel farms conformed to some criteria. Firstly, the sampled farms had to have water visibility consistently greater than 2.5 m so that divers could see to the edge of the transects (Figure 3.1c). Secondly, the mussel farms had to have at least five rows of mussel lines (Figure 3.1a). Thirdly, farms also had to be accessible via a small, rubber, inflatable power boat launched from a beach with road access.

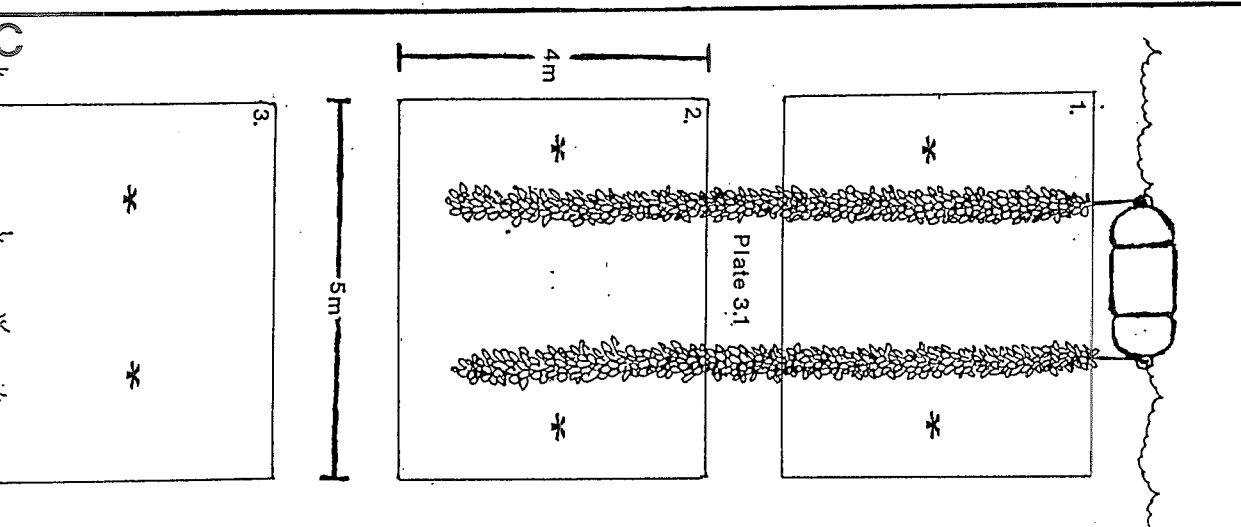
Initially, in autumn of 1991, only two farms were sampled: one in Waitaria Bay ( $174^{\circ}2.5'E$ ,  $41^{\circ}4.5'S$ ), roughly in the centre of Kenepuru Sound, and one in an unnamed bay ( $173^{\circ}56'E$ ,  $41^{\circ}12.5'S$ ) 2.5 km west of Schnapper Point near the mouth of Kenepuru Sound (Figure 1.1). These two farms were repeatedly sampled on a seasonal basis until the summer of 1992 ( $n=8$ ). In the spring of 1991 other suitable farms were found in Otatara Bay ( $174^{\circ}2.5'E$ ,  $41^{\circ}4.5'S$ ) and Clova Bay ( $174^{\circ}2.5'E$ ,  $41^{\circ}5.5'S$ ) in the neighbouring Pelorus Sound (Figure 1.1.). These were also sampled seasonally until the end of 1991 ( $n=4$ ).

Figure 3.1: A) A diagrammatical representation of a typical mussel farm showing the first five mussel lines sampled. The insert (B) shows the location of the areas sampled. B) The locations and dimensions of transects used in the preliminary survey. Transects are numbered according to their description in section 3.2.2. The positions of plates 3.1-3.3 (pages 47 & 48) are also shown. C) A cross-section of a mussel line showing the width and height dimensions of transects 1-3, \*- indicates the positions of the two divers during transects.

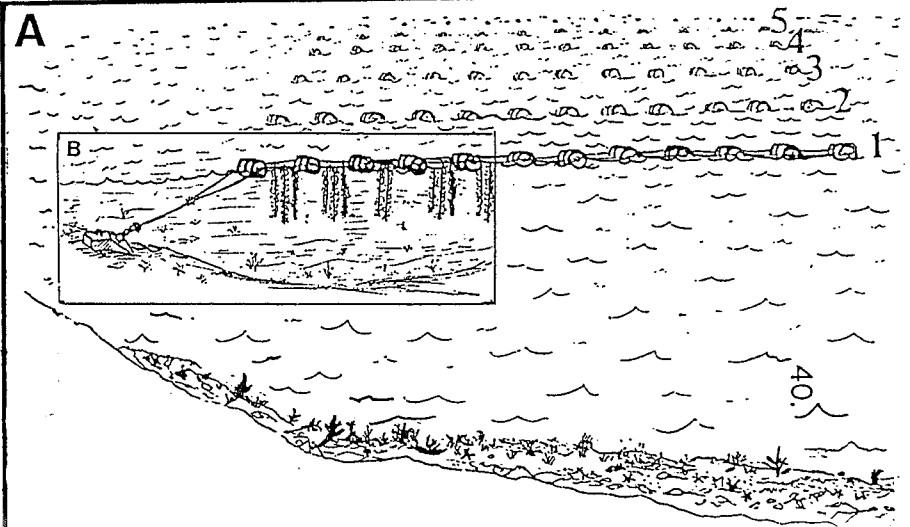
B



C



A



### 3.2.4 Daily variations of fish abundance patterns within a mussel farm

Before undertaking the main survey, it was essential to ensure that fish counts taken at any one time within any one day were representative of all times during days within a season. Therefore, at the beginning of 1992, prior to the main survey, the abundance of *N. celidotus* was repeatedly assessed both within and between days in four positions in a mussel farm in Otatara Bay (174°2'E, 41°5'S, Figure 1.1), Pelorus Sound. This would also ensure that the daily time restrictions placed on visual counts in the preliminary survey (0900-1600 hrs) did not sample across any daily migrations of these fish.

On the first three mussel lines of the farm (Figure 3.2a), the top and bottom meters of the mussel dropper lines were sampled (Figures 3.2b-1 and 2), the seabed below the mussel lines (Figure 3.2b-3) and the seabed below the mooring bridle, including the mooring block (Figure 3.2b-4), were censused at first light, mid-day, and dusk for three consecutive days using 30x5x4 transects. For a detailed description of the transects used to census the four areas, see section 3.2.4 (pages 42-43).

### 3.2.5 Spatial and seasonal variations of fish abundance patterns within mussel farms and adjacent coastal natural areas

From the preliminary survey of *Notolabrus celidotus* on mussel farms done in 1991, it was clear that fish were associated with particular portions of mussel farms (see Results Section 3.3.1). Throughout the year, small juvenile fish were also observed in the macro-algae and encrusting organisms of mooring ropes and in the coastal natural areas adjacent to mussel farms. In addition to the four transect positions used in the preliminary survey of 1991, it was decided to incorporate these two other areas into the sample design for 1992. Six distinct areas of each mussel farm were, therefore, sampled in the secondary survey of the mussel farm environment:

1. The top 4 m of the mussel dropper lines  
(Figure 3.2b-1 and Plate 3.1).
2. The bottom 4 m of the mussel dropper lines  
(Figure 3.2b-2 and Plate 3.1).
3. The seabed directly below the suspended dropper lines  
(Figure 3.2b-3 and Plate 3.2).
4. The concrete mooring block and seabed beneath the mooring rope  
(Figure 3.2b-4 and Plates 3.3 and 3.4).
5. The mooring rope  
(Figure 3.2b-5 and Plate 3.5).
6. The adjacent natural areas  
(Figure 3.2a and Plate 3.6).

So that all areas of interest could be directly compared with a stratified hierarchical sampling design, all transects were set to a standard size (Sale and Sharp, 1983). A constant transect size of 30x5x4 m was agreed upon, not because it necessarily optimised sample precision (Sale and Sharp, 1983; McCormick and Choat, 1987), but because these dimensions were imposed by both structural characteristics of mussel farms and limited water visibility. To sample the benthos below mooring ropes, transects were restricted to a length less than the distance from the mooring block to the benthos directly below mussel lines (See Figure 3.2b). The distance of 30 meters was determined by Hickford (1993) as an optimal length for this type of work. This was also a length that consistently sampled this area without incorporating the habitat sampled in position 3 (below mussel lines). As in the preliminary survey, a transect width of 5 m was chosen to incorporate both pairs of dropper lines sampled in positions 1 and 2 (See Figure 3.2b). A height of 4 m was chosen because visibility often limited any observations made beyond this distance. Thus, all transect sampled 600 m<sup>3</sup> of water.

For each mussel farm, the first five mussel lines (Figure 3.2a) were sampled using the following transects:

1. Along a randomly chosen segment of mussel line, a horizontal 30 m transect was done through the top 4 m of the vertical dropper lines (Figure 3.2b-1). One diver would swim on each side of the dropper lines and record fish observed 2.5 m either side of an imaginary line between the paired dropper lines (Figure 3.2c-1).
2. Along the same segment of mussel line, a horizontal 30 m transect was then done through the bottom 4 m of the vertical dropper lines (Figure 3.2b-2). One diver would swim on each side of the dropper lines and record fish observed 2.5 m either side of an imaginary line between the paired dropper lines (Figure 3.2c-2).
3. A 30 m benthic transect was done on the seabed directly beneath the preceding transects (Figure 3.2b-3). One diver would swim below each of the rows of dropper lines and record fish observed above the seabed 2.5 m either side of an imaginary line between the paired dropper lines (Figure 3.1c-3).
4. A second 30 m benthic transect was done starting at and including the mooring block and continuing along the seabed directly beneath the sampled mooring rope (Figure 3.2b-4).

5. A transect was swum down one of the two mooring ropes (chosen at random) with the divers recording fish present within a radius of 2.5 m of the mooring rope<sup>1</sup> (Figure 3.2b-5).
6. A 30 m benthic transect was done in the shallow natural area of coast directly adjacent to the sampled mussel farm (Figure 3.2a). Within each 30 m transect, fish were observed in six 5x5x4 m blocks. An estimate of the percentage macro-algal cover was also recorded for each of these blocks.

For each mussel farm, five replicate transects were done in positions 1-5 by treating the closest five mussel lines as replicates (Figure 5.2a). On each farm, however, transects of 30 m taken in position 6 could be replicated only three times since mussel lines lying parallel to shore are only 110 m long; there is, therefore, only 110 m of coast-line directly adjacent to each mussel farm (Figure 3.2a). This methodology required that the sampled mussel farms conform to the same criteria as those outlined for the preliminary survey (section 3.2.2).

The preliminary survey in 1991 showed considerable variation in the abundance of juvenile *N. celidotus* between farms in Kenepuru and Pelorus Sounds (See Results Section 3.3.1). However, the farm in Waitaria Bay (Kenepuru Sound) frequently had poor underwater visibility. Therefore in the 1992 survey, two farms were sampled in an unnamed bay (173°56'E by 41°12.5'S) 2.5 km west of Schnapper Point in Kenepuru Sound (Figure 1.1). Two farms were also sampled in Elie Bay (174°E by 41°7.5'S), Pelorus Sound (Figure 1.1). These four farms and their adjacent natural areas were repeatedly sampled on a seasonal basis for one year from autumn 1992.

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<sup>1</sup> The length of the anchor line, as the hypotenuse of a right-angled triangle, is always greater than the distance from the mooring block back to the mussel line benthos (transect 3). Therefore, the anchor lines were always more than 30 m long, on average 32 m. However, since the transects for position 5 were tubular, the resulting volume of water sampled was on average 628 m<sup>3</sup>.



This sampling model was designed to investigate factors influencing the abundance patterns of *N. celidotus* at a number of spatial levels. However, due to the scale of the survey, one spatial level was not replicated seasonally. Only one bay was sampled within each sound; consequently this may not be representative of the entire sound. In an effort to measure patterns of fish abundance between bays of the same sound, an extra bay in each sound was sampled in both the autumn and summer seasonal surveys. In Kenepuru Sound, two extra mussel farms and their adjacent natural areas were sampled in an area known as Skiddaw ( $173^{\circ}54'E$  by  $41^{\circ}12'S$ ), on the opposite side of the sound and 3.5 km west of the farms sampled near Schnapper Pt (Figure 1.1). This was the only other area in Kenepuru Sound with water visibility consistently good enough to allow regular fish counts. Kenepuru (meaning "silt" in Maori) had drastically reduced visibility towards its inner end. In Pelorus Sound, two extra mussel farms and their adjacent natural areas were sampled in Clova Bay ( $174^{\circ}25'E$  by  $41^{\circ}5.5'S$ ), 8.5 km north-east of the farms sampled in Elie Bay (Figure 1.1).

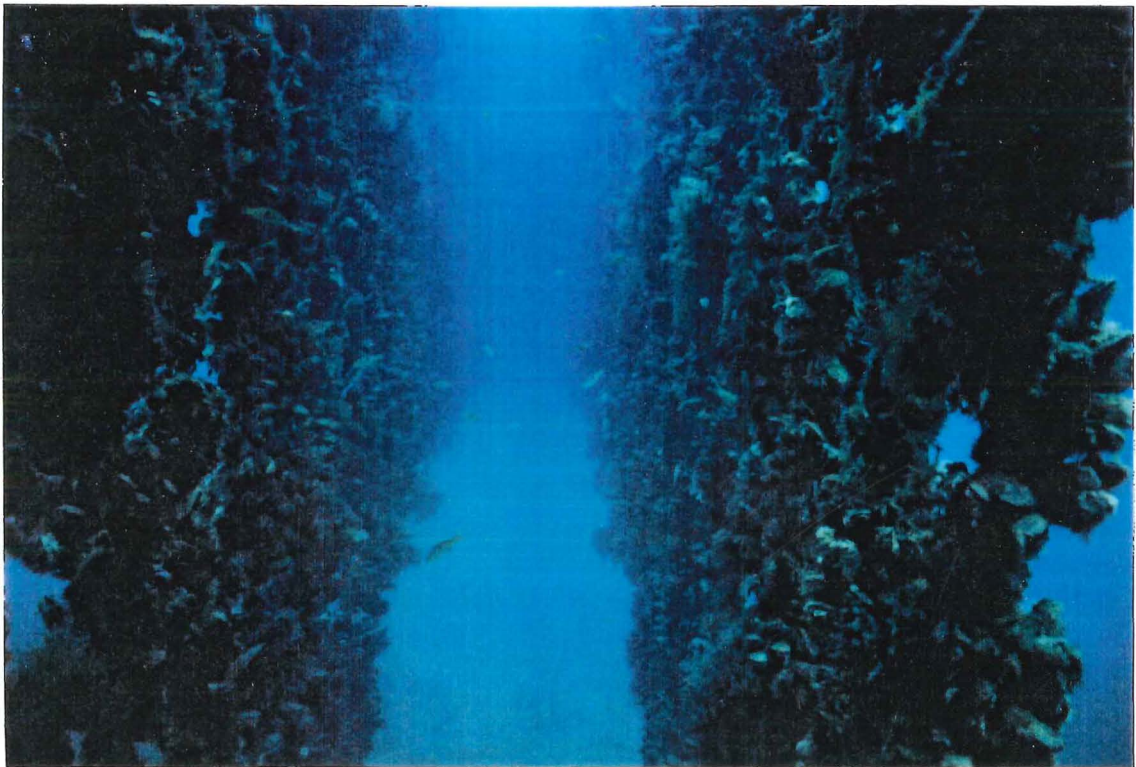
### 3.2.6 Treatment of data

Most reef fish are patchily distributed on a surprisingly small scale compared to the range of movement that these animals are capable of; this is a reflection of the heterogeneous nature of their environment (Sale *et al*, 1985). For this reason, the frequency data sets gathered in visual counts of reef fish are characterised by (i) small mean values, (ii) skewed frequency distributions, and (iii) large and often unequal variances. Hence reef fish abundance data analysis can be difficult (Sale *et al*, 1985).

Homogeneity of variance was, therefore, tested prior to Analysis of Variance using the Bartlett's test and, if necessary, data was transformed (Sokal and Rolf, 1981). The variance components of the ANOVA model were partitioned to assess the proportion of the total variance due to each factor (Winer, 1971). The relative importance of unknown factors was estimated by dividing the mean square estimate for each factor by the total mean square estimate (Winer, 1971).

All means given both in text and in figures are accompanied by a standard error. Correlations were performed using the Pearson's correlation coefficient, provided the data could be transformed to a normal distribution (Sokal and Rolf, 1981; Bray, 1989).

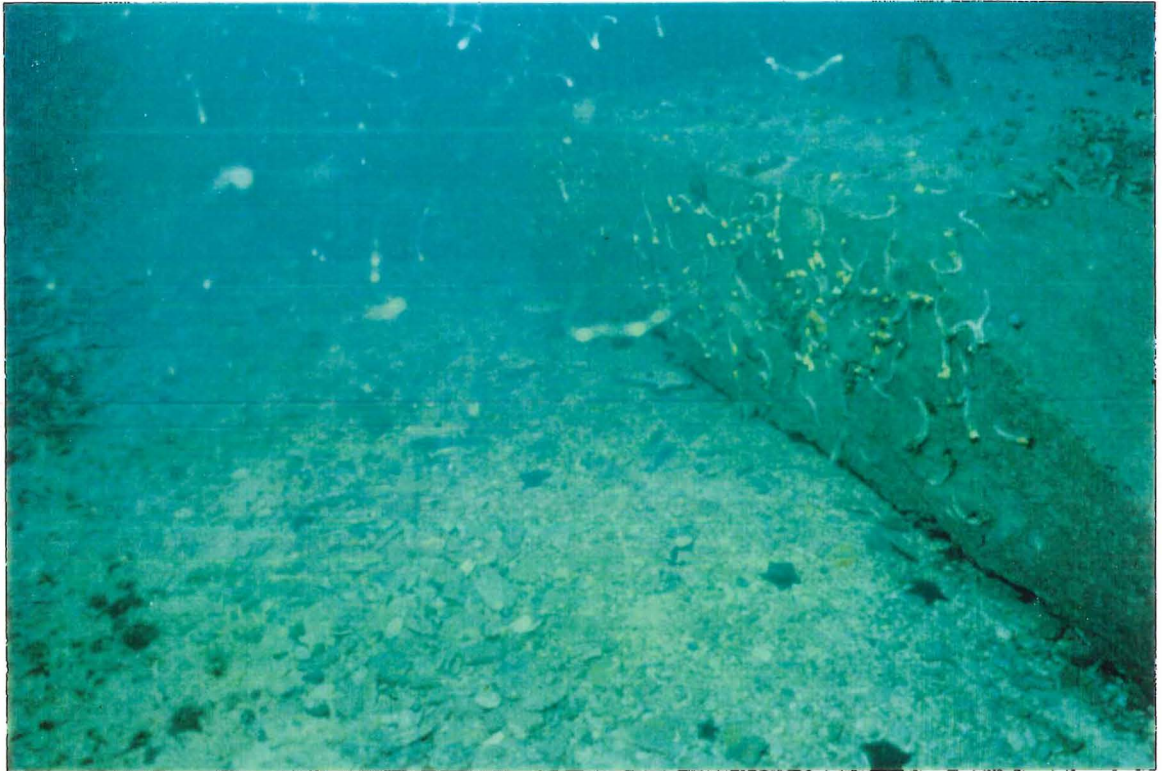
**Plate 3.1** A view down the centre of a mussel line showing the two rows of suspended dropper lines, transect positions 1 and 2.



**Plate 3.2** Typical sea bed directly beneath a mussel line, transect position 3.



**Plate 3.3** A mooring block, transect position 4.



**Plate 3.4** Typical sea bed directly beneath a mooring rope, transect position 4.



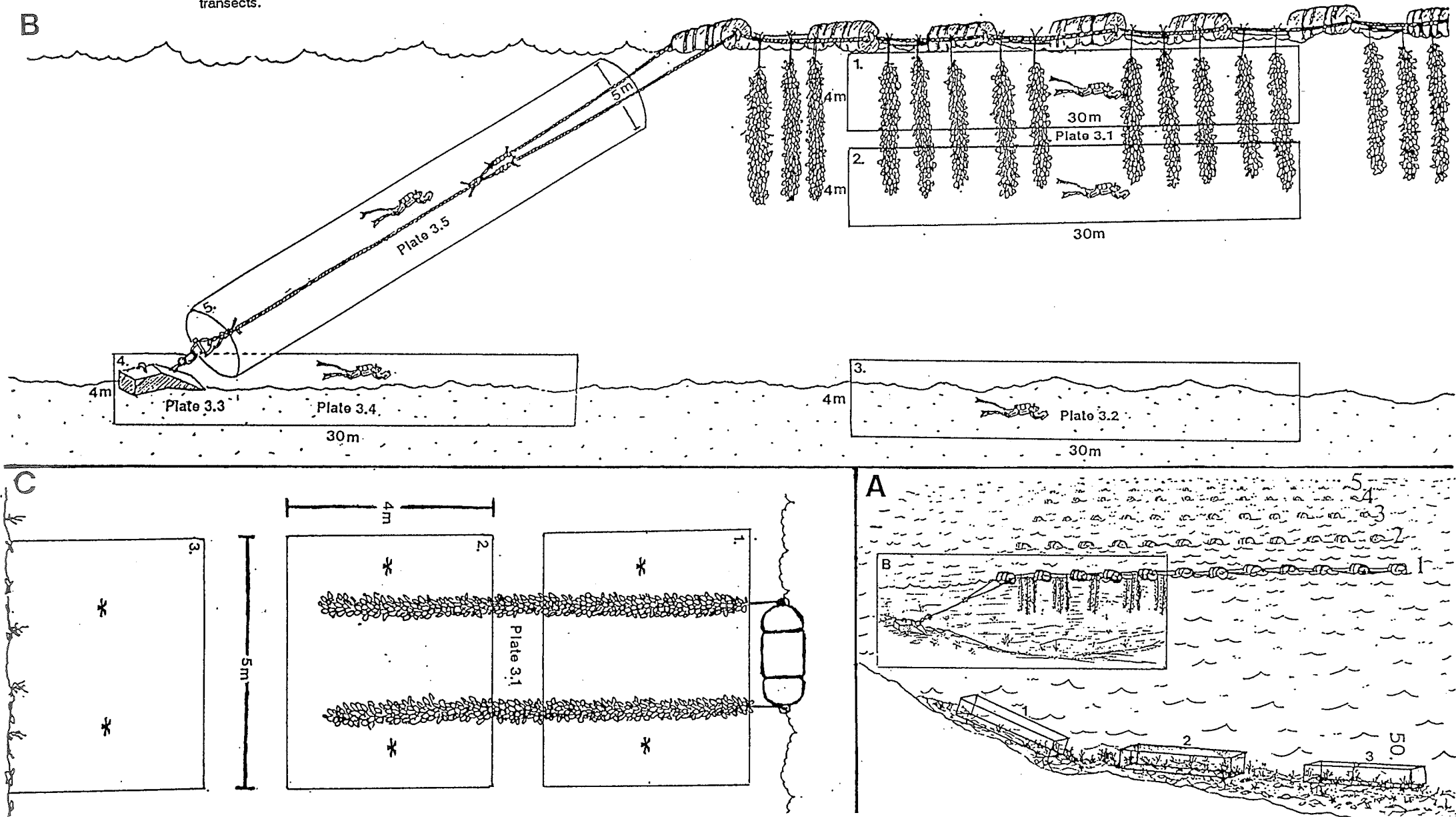
**Plate 3.5** A typical algal covered mooring rope, transect position 5.



**Plate 3.6** Algae-covered broken rock habitat; these were scattered in patches throughout the sand and gravel of the subtidal zones adjacent to mussel farms, transect position 6.



Figure 3.2: A) A diagrammatical representation of a typical mussel farm showing the first five mussel lines sampled. The insert (B) shows the location of the areas sampled. Marked on the adjacent shoreline are the three subtidal transects also sampled. B) The locations and dimensions of the transects used in the main survey, transects are numbered according to their description in section 3.2.3. The positions of plates 3.1-3.6 (pages 47-49) are also shown. C) A cross-section of a mussel line showing the width and height dimensions of transects 1-3, \*- indicates the positions of the two divers during transects.



### 3.3 RESULTS

#### 3.3.1 Preliminary survey of mussel farms

The preliminary survey of *Notolabrus celidotus* showed clearly that farms sampled in the Pelorus Sound had higher densities of young fish (<120mm SL) than those sampled in Kenepuru Sound in 1991 (Figure 3.3). However, patterns of abundance were more similar among farms situated in different bays of the same sound than between bays of different sounds (Figure 3.3). A seasonal effect was also observed as *N. celidotus* were rare in Kenepuru Sound on over autumn and virtually absent in winter (Figure 3.1). This temporal variation apparently occurs over a large spatial scale, as fish numbers also peaked in summer (Figure 3.3).

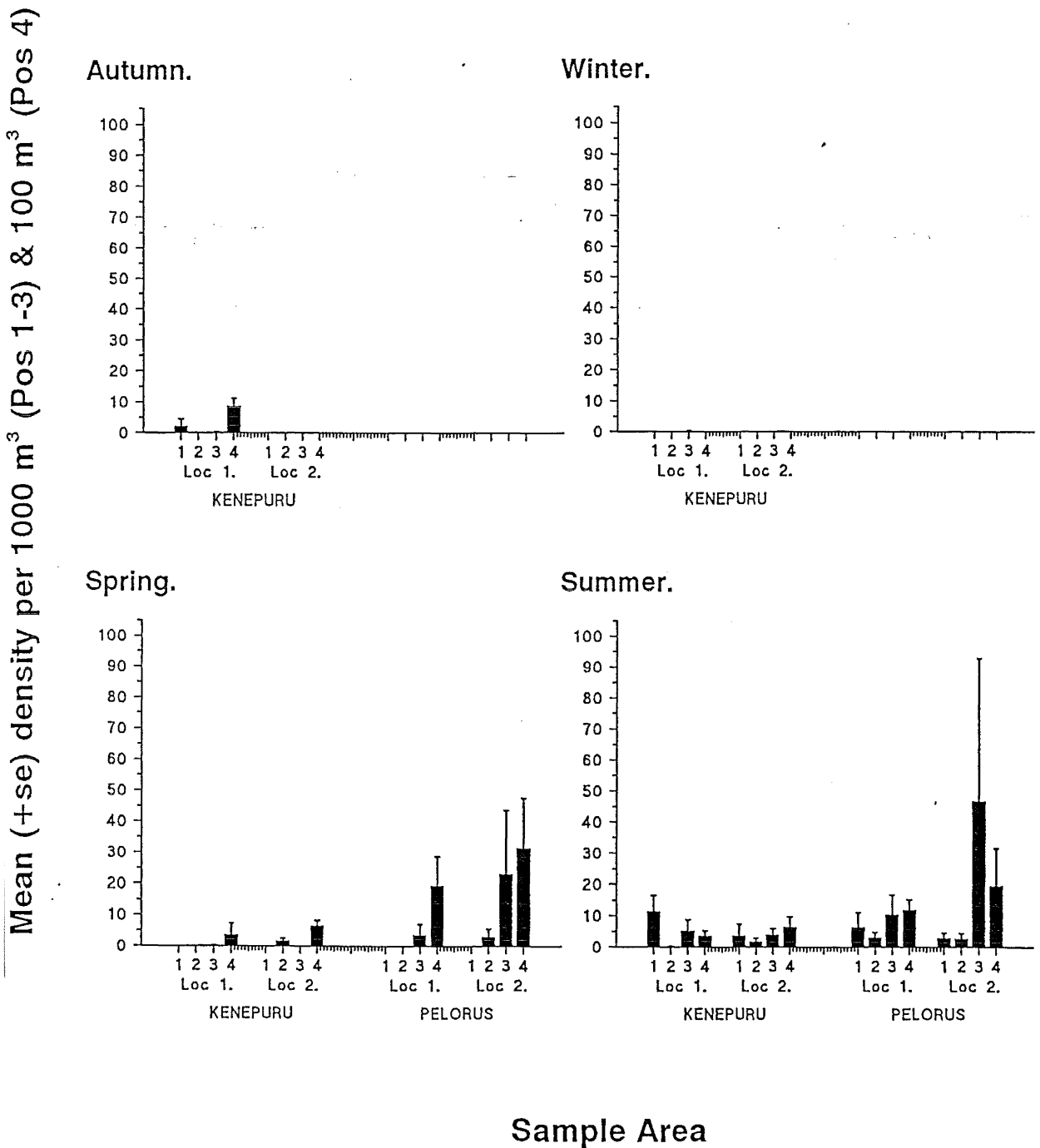
In all seasons and regional locations, positions sampled on each farm contained distinctly different numbers of *N. celidotus*. In particular, densities were consistently higher around the mooring blocks (Figure 3.2b-4) of all farms (Figure 3.3, note the difference in transect sizes). Much more variability was seen in the densities of *N. celidotus* observed in the other three positions (Figure 3.3). These fish were, evidently, most associated with the mooring blocks, although the tops of the dropper lines and the benthos below them also became important latter in the year (Figure 3.3). Young *N. celidotus* were consistently rare on the bottom half of the dropper lines (Figure 3.3).

Unfortunately, the data collected in this survey had heterogeneous variances within cells both before and after transects were calibrated to the smallest transect size (100 m<sup>3</sup>). Even the most effective transformation (Bartlett's Test for square-root transformation:  $M/C=55.55_{(31)}$ ,  $P<0.005$ ) did not stabilise the variances as is required before an ANOVA can be done (Sokal and Rohlf, 1981). Consequently, no statistical analysis was carried out on this data.

From this pilot study, it was clear that within the structures of mussel farms young *N. celidotus* were not distributed randomly. As well, notable differences were also attributable to larger-scale spatial variations (i.e., between sounds) (Figure 3.3). Consequently, a more detailed sample design would be required in the main survey to effectively explain variations in densities of *N. celidotus* both within and between mussel

farms of Kenepuru and Pelorus Sounds. A standardised transect size would also be required.

Figure 3.3: Mean (+se) numbers of juvenile *Notolabrus celidotus* (<120 mm SL) observed seasonally in the preliminary survey (1991) in 4 positions, (n=5) of mussel farms. Sampled positions were: 1=top 4 m of dropper lines; 2=bottom 4 m of dropper lines; 3=benthos below dropper lines; 4=mooring block. Positions 1-3 were sampled with 1000 m<sup>3</sup> transects, whereas position 4 was sampled with only 100 m<sup>3</sup> transects. Each sampled farm was located in one of two bays within each of the Kenepuru (Loc1=Waitaria Bay, Loc2=Schnapper Pt) and Pelorus Sounds (Loc1=Otatarata Bay; Loc2=Clova Bay).





### 3.3.2 Daily variations of fish abundance patterns within a mussel farm

Replicate observations of fish numbers both within and between days showed that densities of young *Notolabrus celidotus* (<120mm) remained consistently higher around the mooring blocks than in the other three parts of the mussel farm surveyed (Figure 3.4). Consequently, variations in the densities of these fish were highly significant between positions within the mussel farm (Table 3.1). This factor alone accounted for virtually all of the explained partitioned variance in the ANOVA of this data (Table 3.1). More than 50% of the observed variation in densities of *N. celidotus* on this mussel farm remained unexplained (Table 3.1).

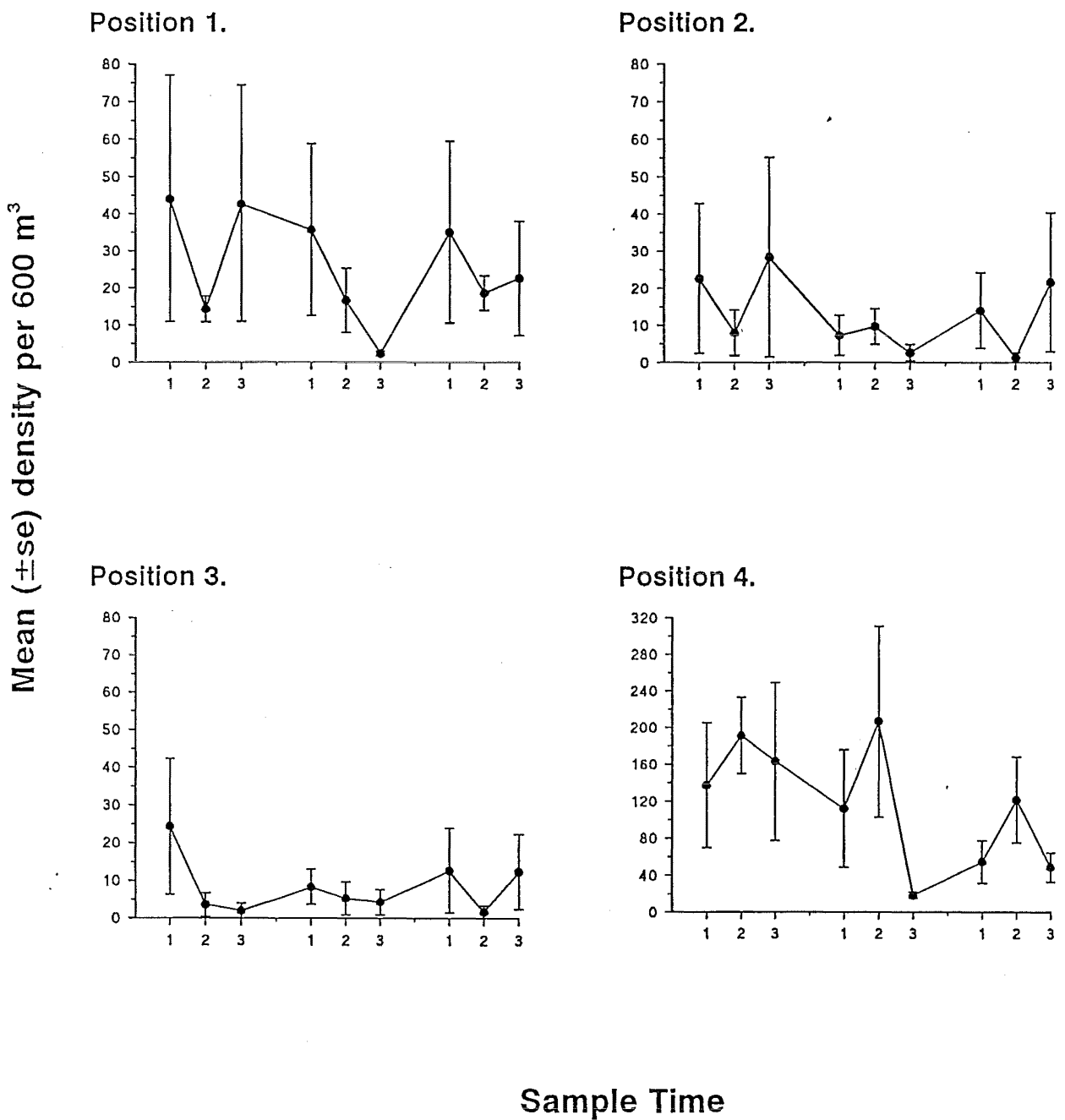
Nonetheless, over the three days surveyed there was, at noon, a consistent slight daily increase in the abundance of *N. celidotus* on mooring blocks (Figure 3.4). This coincided with a regular decrease in numbers observed in the other areas surveyed (Figure 3.4); however, this factor was not significant (Table 3.1).

These results show that densities of juvenile *N. celidotus* remain relatively stable in areas within and between days (Figure 3.4 and Table 3.1). Consequently, samples taken within the regime of the main survey reported in this chapter are expected to be representative of each sample period (Section 3.3.2).

**Table 3.1:** The effects of short term temporal variations on densities of juvenile *Notolabrus celidotus* counted in 4 positions of a mussel farm, 3 times a day, for 3 days. Data was transformed to its natural logarithm (Bartlett's Test:  $M/C=0.860_{(33)}$ , ns). The percentages of the total variance accounted for by each factor are given; formula from Winer (1971).

Source	df	MS	F	P	%
Position	3	48.510	27.07	<0.001	48.8
Day	2	2.481	1.38	0.257	0.5
Time(Day)	6	1.873	1.05	0.404	0.1
Position*Day	6	0.673	0.38	0.892	0.0
Position*Time(Day)	18	1.017	0.57	0.911	0.0
Residual	72	1.792			50.5
Total	107				

Figure 3.4: Mean ( $\pm$ se) numbers of juvenile *Notolabrus celidotus* (<120 mm SL) observed in 4 positions of a mussel farm in Otatara Bay (Pelorus Sound). Observations were made 3 times a day over a 3 day period. Positions sampled were,  $(n=3)$ : 1=top 4 m of dropper lines; 2=bottom 4 m of dropper lines; 3=benthos below dropper lines; 4=mooring block and benthos below mooring rope. Samples were taken at times: 1=first light; 2=mid-day and 3=dusk over three consecutive days.



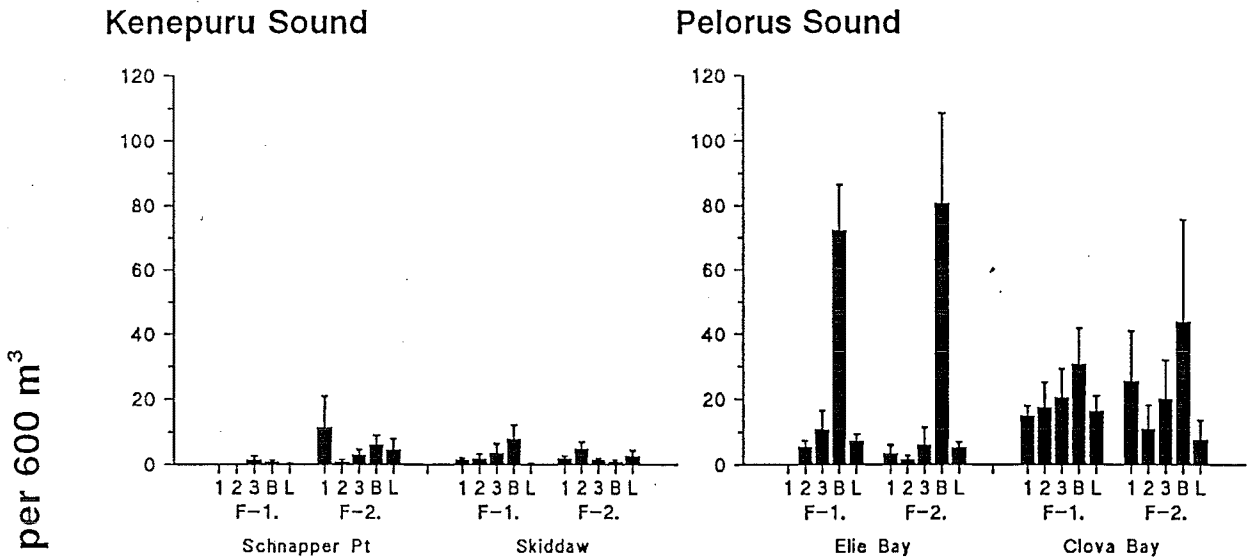
### 3.3.3 Patterns of distribution and abundance

Half-yearly observations of young *N. celidotus* (<120mm SL) were done on two replicate mussel farms within two bays each in Kenepuru and Pelorus Sounds. These showed that levels of abundance were more alike between farms of the same bay than between farms situated in different bays of the same sound (Figure 3.5). However, as in the preliminary survey of 1991, levels of abundance were more similar among farms situated in different bays of the same sound than between bays of different sounds (Figure 3.3). Unfortunately, an ANOVA could not be carried out on data collected between bays of the same sound because levels of heterogeneity within sample variances were too high and could not be corrected by any transformation (Bartlett's Test:  $M/C=655.855_{(63)}$ ,  $P<0.001$ ). Nonetheless, results of the bi-yearly survey tend to indicate that factors indicative of the regional differences between Kenepuru and Pelorus Sounds have more effect on the level of *N. celidotus* abundance than do localised factors indicative of the differences between bays in the same sound (Figure 3.5).

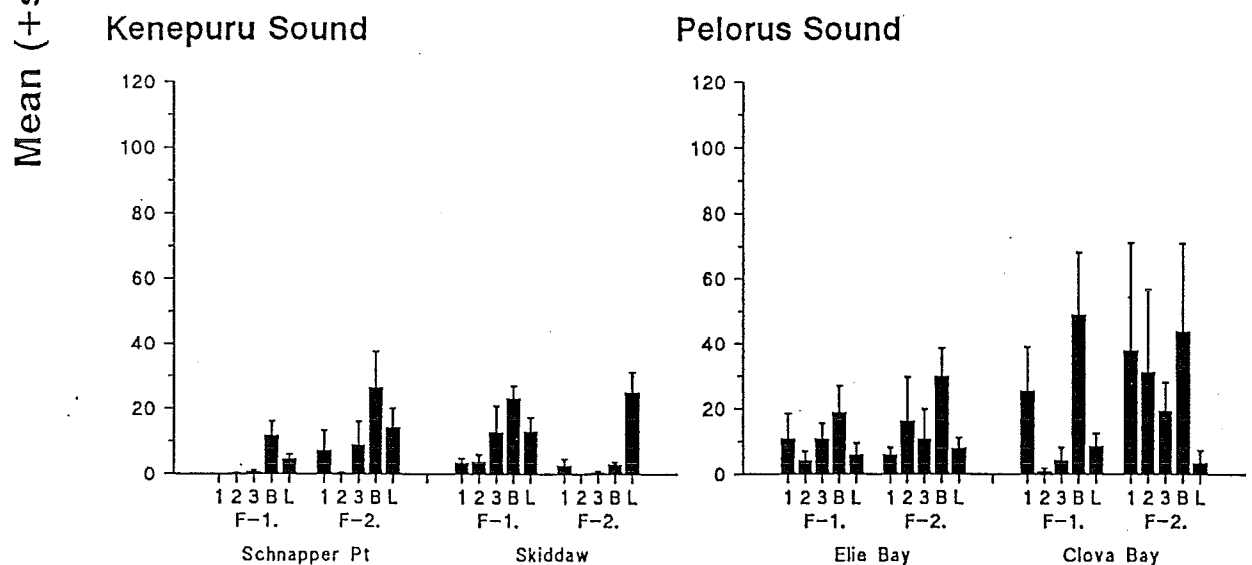
Despite variations observed in numbers of *N. celidotus* over both large (between sounds) and small (between bays) spatial scales, a basic pattern again emerges in the distribution of these fish (Section 3.3.1). Within all four mussel farms, transects done on the mooring blocks and associated benthos (Figure 3.2b-4) had the highest densities of fish at most observation periods (Figure 3.5). Although considerable spatial and temporal variations of this trend were observed, more variability was seen among the other positions (1-3) sampled (Figure 3.5). Densities in these positions also appeared to be more affected by the temporal component studied in this survey (Figure 3.5).

Figure 3.5: Mean (+se) numbers of juvenile *Notolabrus celidotus* (<120 mm SL) observed in 5 positions of mussel farms sampled bi-yearly in 1992. Two mussel farms were sampled in each of two bays within both Kenepuru and Pelorus Sounds. Positions sampled were,  $(n=5)$ : 1= top 4 m of mussel dropper lines; 2= bottom 4 m of mussel dropper lines; 3= benthos below mussel dropper lines; B= mooring blocks and benthos below mooring ropes; L= mooring ropes (lines). For specific locations and dimensions of transects used see section 3.2.4.

**AUTUMN**



**SUMMER**



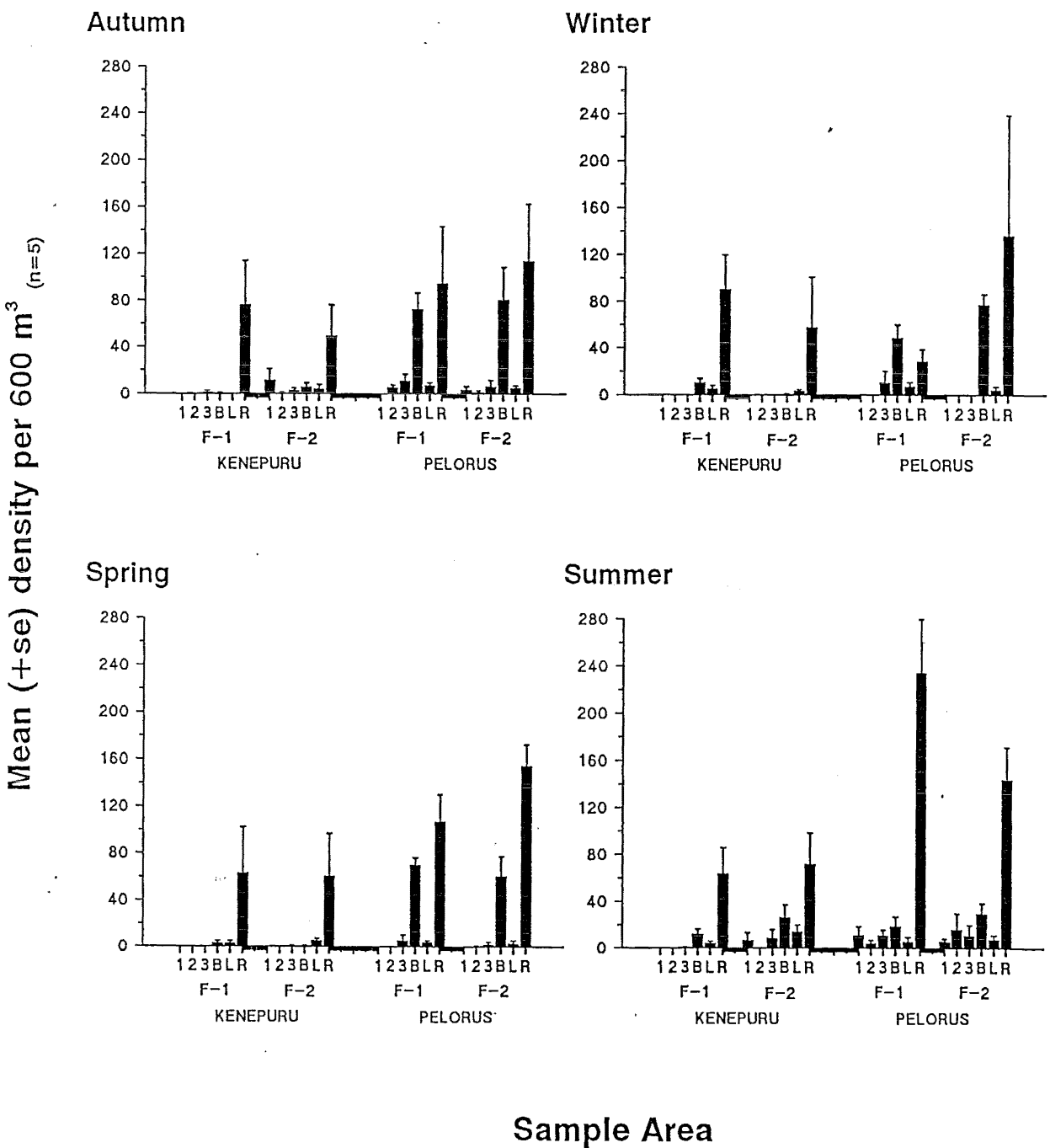
Sample Time

So far, densities of young *N. celidotus* (<120mm SL) observed on mussel farms have been clearly greater in sites of Pelorus Sound than in Kenepuru Sound (Figures 3.3 and 3.5). This was again seen in the seasonal observations of the main survey (Figure 3.6). However, in this survey transects were also done in natural areas adjacent to mussel farms (Figure 3.2a). These consistently had more young *N. celidotus* than did transects done in adjacent mussel farms (Figure 3.6).

Square root transformations stabilized the variance and ANOVAs could be done (Tables 3.2 and 3.3). The numbers of *N. celidotus* sampled within mussel farms were significantly dependent upon which sound the sample was taken in (Table 3.2). The 'SOUND' factor alone accounted for 13% of portioned variance in the ANOVA and was part of two other significant interactions (Table 3.2). Numbers of *N. celidotus* observed in natural areas adjacent to surveyed mussel farms were also influenced by this factor (Table 3.3). Differences between sounds, although highly significant accounted for just 7% of the portioned variance in the ANOVA for these areas (Table 3.3). The abundances of young *N. celidotus* observed in natural areas were probably less influenced by environmental factors at a regional scale between Kenepuru and Pelorus Sounds than were fish observed on mussel farms. The location of farms within bays was not significant for *N. celidotus* observed on either mussel farms (Table 3.2) or in their adjacent natural areas (Table 3.3).

The spatial factors which accounted for most of the observed variation in the abundance patterns of young *N. celidotus* were on a very localised scale. Differences in transect locations within mussel farms (Figure 3.2b) demonstrated a highly significant effect on the distribution of these fish (Table 3.2). This factor alone accounted for 46% of the portioned variance of this ANOVA (Table 3.2). Hence, these fish are highly associated with specific areas within mussel farms. No such level existed in the ANOVA of fish observed in natural areas adjacent to farms as only one transect position was used (Figure 3.2a). However, because 30 m transects done in natural areas were divided into six 25 m<sup>2</sup> blocks, a mean and variance was associated with each transect. Differences in the abundance of fish observed between these transects were highly significant showing how patchy *N. celidotus* are distributed at this scale.

Figure 3.6: Mean (+se) numbers of juvenile *Notolabrus celidotus* (<120 mm SL) observed seasonally in 6 positions of the mussel farm environment. Positions sampled were, (n=5): 1= top 4m of droppers; 2=bottom 4m of droppers; 3=benthos below droppers; B=mooring block and benthos below mooring lines; L=mooring lines; R=adjacent coastal subtidal areas (n=9). Two mussel farms were sampled in a single bay of each the Kenepuru (Schnapper Pt) and Pelorus Sounds (Elie Bay). For specific locations and dimensions of transects used see section 3.2.4.



**Table 3.2** The effects of season, location, site and transect positions on densities of young *Notolabrus celidotus* (<120 mm SL) observed on mussel farms. Two mussel farms were surveyed in one bay of both Kenepuru and Pelorus Sounds. Samples were taken seasonally during 1992. Transect positions are shown in Figure 3.2b. Data was transformed to its square root ( $x+1$ ) (Bartlett's Test:  $M/C=2.2711_{(79)}$ , ns). The percentages of the total variance accounted for by each factor are given; formula from Winer (1971).

Source	df	MS	F	p	%
Season	3	15.51	6.37	<0.001	2
Sound	1	214.99	88.20	<0.001	13
Farm(Sound)	2	4.28	1.76	0.174	0
Position(Sound Farm)	16	77.47	31.79	<0.000	46
Season*Sound	3	5.45	2.24	0.084	1
Season*Farm(Sound)	6	3.85	1.58	0.152	1
Season*Pos(Sound Farm)	48	5.24	2.15	<0.001	7
Residual	320	2.43			30
Total	399				

**Table 3.3:** The effects of season, location, site and transects on densities of young *Notolabrus celidotus* (<120 mm SL) observed in natural areas adjacent to sampled mussel farms. Areas adjacent to two farms were surveyed in one bay of both Kenepuru and Pelorus Sounds. Samples were taken seasonally during 1992. Data was transformed to its square root ( $x+1$ ) (Bartlett's Test:  $M/C=43.567_{(47)}$ , ns). The percentages of the total variance accounted for by each factor are given; formula from Winer (1971).

Source	df	MS	F	p	%
Season	3	24.28	8.25	<0.001	4
Sound	1	88.52	30.09	<0.001	7
Farm(Sound)	2	6.39	2.17	0.116	0
Transect(Sound Farm)	8	19.32	6.56	<0.001	9
Season*Sound	3	21.70	7.34	<0.001	6
Season*Farm(Sound)	6	7.14	2.43	0.027	3
Season*Transect(Sound Farm)	24	19.02	6.47	<0.001	34
Residual	240	2.94			37
Total	287				

The dominate macro-algae observed in natural transects was *Cystophora scalaris*. It was significantly more abundant in Pelorus Sound (Figure 3.7 and Table 3.4). An ANOVA done on the percentage macro-algal cover recorded in each 25 m<sup>2</sup> block of natural areas showed there were highly significant differences between individual transects both within and between sites of sampled bays (Table 3.4). This reflects not only the heterogenous nature of marco-algal cover in the natural environment adjacent to sampled mussel farms but also shows that levels of macro-algal cover are highly variable among sites within bays.

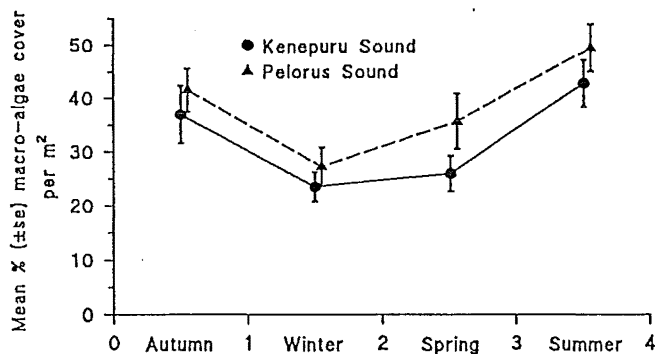
A correlation between the total number of young *N. celidotus* and the percentage macro-algal cover showed that a strong, positive relationship existed between these two factors ( $P=0.487_{(46)}$ ,  $p<0.001$ ).

Table 3.4: The effects of season, location, site and transects on percentage macro-algal cover observed in natural areas adjacent to sampled mussel farms. Areas adjacent to two farms were surveyed in one bay of both Kenepuru and Pelorus Sounds. Samples were taken seasonally during 1992. Data not transformed ( $C=0.093_{(6,48)}$ , ns). The percentages of the total variance accounted for by each factor are given; formula from Winer (1971).

Source	df	MS	F	p	%
Season	3	6025.8	23.56	<0.001	8
Sound	1	2744.2	10.73	0.001	2
Farm(Sound)	2	14983.3	58.59	<0.001	19
Transect(Sound Farm)	8	4511.7	17.64	<0.001	17
Season*Sound	3	128.2	0.50	0.682	0
Season*Farm(Sound)	6	1765.3	6.90	<0.001	8
Season*Transect(Sound Farm)	24	1754.4	6.86	<0.001	23
Residual	240	255.7			24
Total	287				



Figure 3.7: Mean  $(n=36)$  percentage macro-algal cover observed seasonally in natural subtidal areas adjacent to sampled mussel farms. Two sites adjacent to mussel farms were sampled in a single bay of each the Kenepuru (Schnapper Pt) and Pelorus Sounds (Elie Bay).



The seasonal effect on total abundance of young *N. celidotus* was also significant in both surveyed mussel farms (Table 3.2) and in adjacent natural areas (Table 3.3). However, this factor accounted for more of the portioned variance in natural areas than on mussel farms. The seasonal effect on the overall percentage macro-algal cover in areas was also highly significant at this level, but accounted for more of the portioned variance (8%) in the equivalent ANOVA (Tables 3.4).

The effects of seasonal changes on both densities of young *N. celidotus* and macro-algal cover were most evident at the smallest scales observed (Tables 3.2, 3.3 and 3.4). Highly significant differences were detected in the numbers of *N. celidotus* observed in positions of mussel farms replicated over seasons (Table 3.2). This factor accounted for 7% of the portioned variance from observations of fish on mussel farms (Table 3.2). However, the effect of seasonal changes on a small spatial scale were more severe in areas adjacent to mussel farms (Table 3.4).

In natural areas, both densities of *N. celidotus* and percentage macro-algal cover recorded in each 25 m<sup>2</sup> block showed a highly significant difference between individual transect replicated seasonally both within and between sites of sampled bays (Table 3.3 and 3.4). Seasonal differences between transects at the same site, however, accounted for most of the explained portioned variance of both levels of *N. celidotus* (34%) and macro-algal cover (23%). This shows that fish and macro-algae are not only spatially

but also temporally very patchy in the distribution throughout natural areas (Table 3.2 and 3.3).

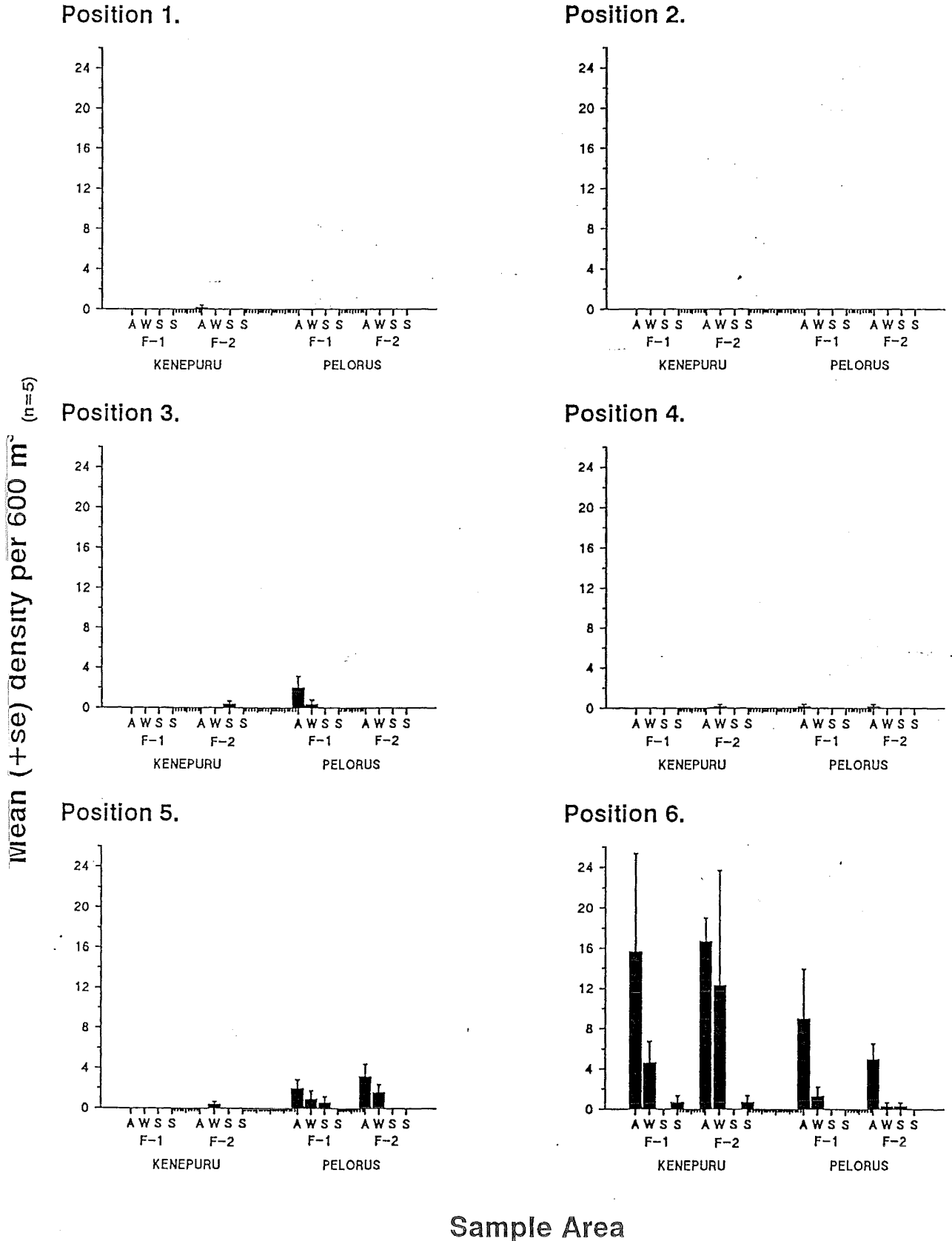
Interestingly, in natural areas the effect of seasons was significantly different for fish densities within each sound (Table 3.3), but not so for macro-algal cover (Table 3.4). It seems that factors indicative of the regional differences between the Kenepuru and Pelorous Sounds regulate the degree to which seasonal shifts effect the abundance patterns young *N. celidotus*, but not macro-algae, in natural areas.

#### 3.3.4. Size class distributions

The larvae of *Notolabrus celidotus* settle out of the plankton and recruit as tiny juveniles (<20mm) into shallow macro-algae (Ayling, 1987). Fish of this size were observed mainly in autumn and winter, but also as late as spring (Figure 3.8). On mussel farms a few newly recruited fishes were observed on the seabed below mussel lines and among encrustations growing on mooring ropes (positions 3 and 5, Figure 3.8). However, the vast majority of the newly recruited *N. celidotus* were observed in natural areas adjacent to sampled mussel farms (position 6, Figure 3.8). Densities of new recruits in these areas of Kenepuru Sound were more than twice those observed in Pelorus Sound (Figure 3.8). This implies more recruitment occurred in Kenepuru Sound than in Pelorus Sound. However, numbers of these small fish were disproportionately low compared to densities of other size classes. This suggests that most of these fish were not seen, probably due to their cryptic appearance among macro-algal cover. Although these results may not be an accurate estimate of the actual levels of recruitment, they are still useful as a comparison between areas.

An inverse relationship, therefore, existed between the total number of juveniles and newly settled *N. celidotus* observed in both sites of each sound. However, this relationship was observed at opposite extremes in each Sound; i.e., sites in Pelorus Sound had many juveniles (Figure 3.6) and few new recruits (Figure 3.8), whereas sites in Kenepuru Sound had relatively few juveniles (Figure 3.6) and many new recruits (Figure 3.8). The same relationship was also observed between densities of adult *N. celidotus* (See Chapter Four and Clarke, 1993) and numbers of newly recruited fish.

Figure 3.8: Mean (+se) numbers of newly recruited *Notolabrus celidotus* (<20 mm SL) observed in positions of mussel farms sampled over the four seasons of 1992. Position 1=top 4m of droppers; Position 2=bottom 4m of droppers; Position 3=benthos below droppers; Position 4=mooring block and benthos below mooring rope; Position 5=mooring rope; Position 6=adjacent subtidal zones (n=3). A=Autumn, W=Winter, S=Spring, S=Summer.

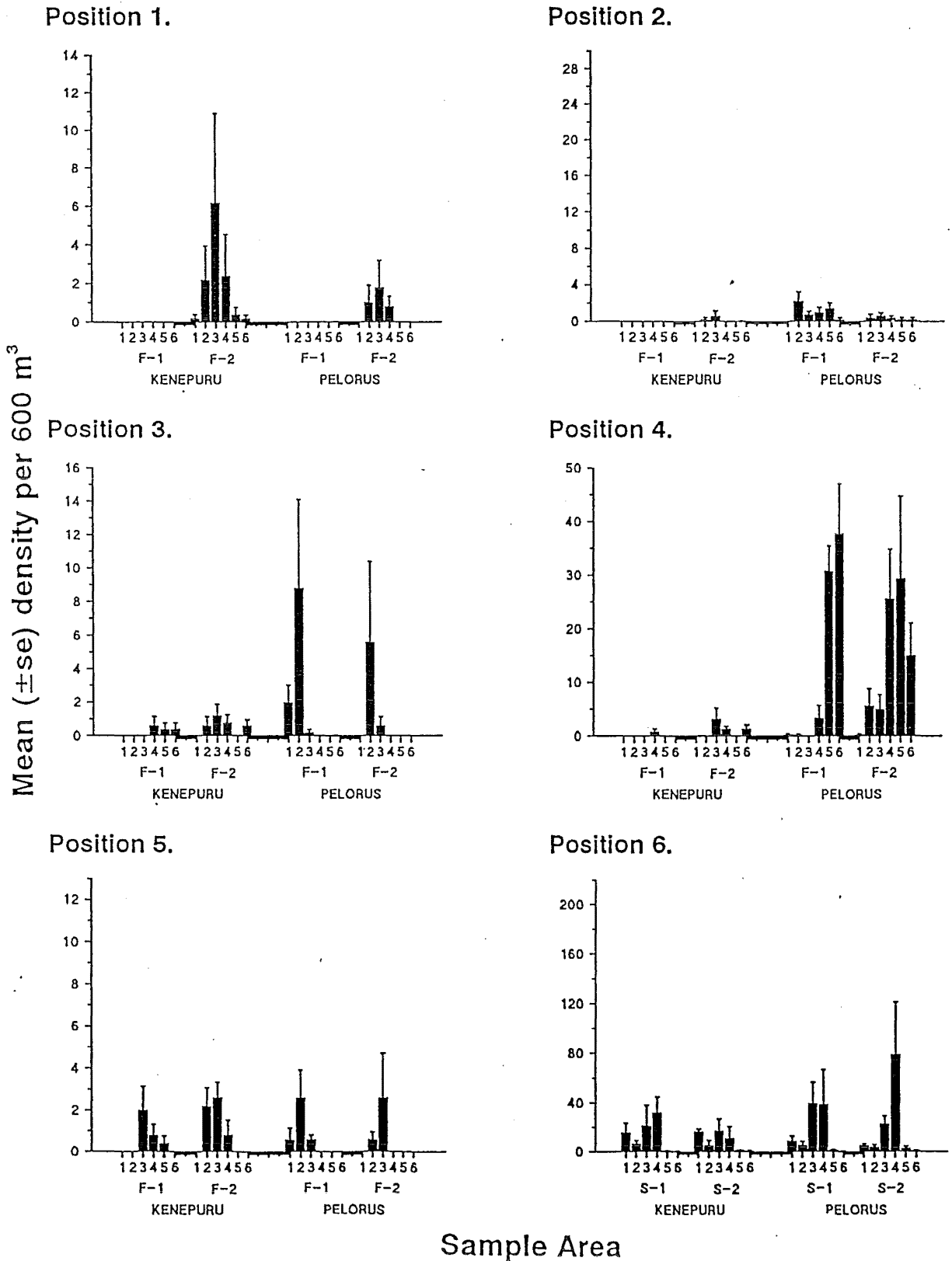


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Figures 3.9 to 3.12 show 20 mm (SL) size classes of juvenile *Notolabrus celidotus* observed in each of the six positions over the four sampled seasons. In most seasons the sea directly below the mussel lines (position 3) was dominated by both small and large fish. Consequently, the graphs of this position show no consistent trends in the distribution of the size classes (Figures 3.9-3.12). However, the mooring block and surrounding seabed (position 4) reported predominantly larger juvenile fish, showing a right-skewed distribution in all four seasons (Figures 3.9-3.12). The reverse was true of fish observed on the dropper lines (positions 1 and 2), mooring ropes (position 5) and adjacent natural areas (position 6) (Figures 3.9-3.12). In these areas, fish were predominantly small and always showed a left-skewed distribution (Figures 3.9-3.12). The fulcrum point distinguishing the left-skewed size-class distributions observed in positions one, two, five, and six, from the right-skewed size-class distribution of position four was 80 mm (SL) (Figures 3.9-3.12).

Areas dominated by juvenile *Notolabrus celidotus* less than 80 mm (SL) were characterised by shallow depth (Figure 3.2a and b) and moderate macro-algal cover (Plates 3.1, 3.5, and 3.6), while areas with fish greater than 80 mm were deeper (Figure 3.2b) and had little to no macro-algal cover (Plates 3.2, 3.3 and 3.4).

Figure 3.9: Autumn (1992) mean ( $\pm$ se) size classes of juvenile *Notolabrus celidotus* (<120 mm SL) observed in the six sampled positions. Sample positions were  $(n=5)$ : position 1=top 4 m droppers; position 2=bottom 4 m droppers; position 3=benthos below droppers; position 4=mooring block and benthos below mooring rope; position 5=mooring rope; position 6=adjacent subtidal zones  $(n=3)$ . Size classes (SL) are: 1=0-20 mm; 2=21-40 mm; 3=41-60 mm; 4=61-80 mm; 5=81-100 mm; 6=101-120 mm.



**Figure 3.10:** Winter (1992) mean ( $\pm$ se) size classes of juvenile *Notolabrus celidotus* (<120 mm SL) observed in the six sampled positions. Sample positions were<sub>(n=5)</sub>: position 1=top 4 m droppers; position 2=bottom 4 m droppers; position 3=benthos below droppers; position 4=mooring block and benthos below mooring rope; position 5=mooring rope; position 6=adjacent subtidal zones<sub>(n=3)</sub>. Size classes (SL) are: 1=0-20 mm; 2=21-40 mm; 3=41-60 mm; 4=61-80 mm; 5=81-100 mm; 6=101-120 mm.

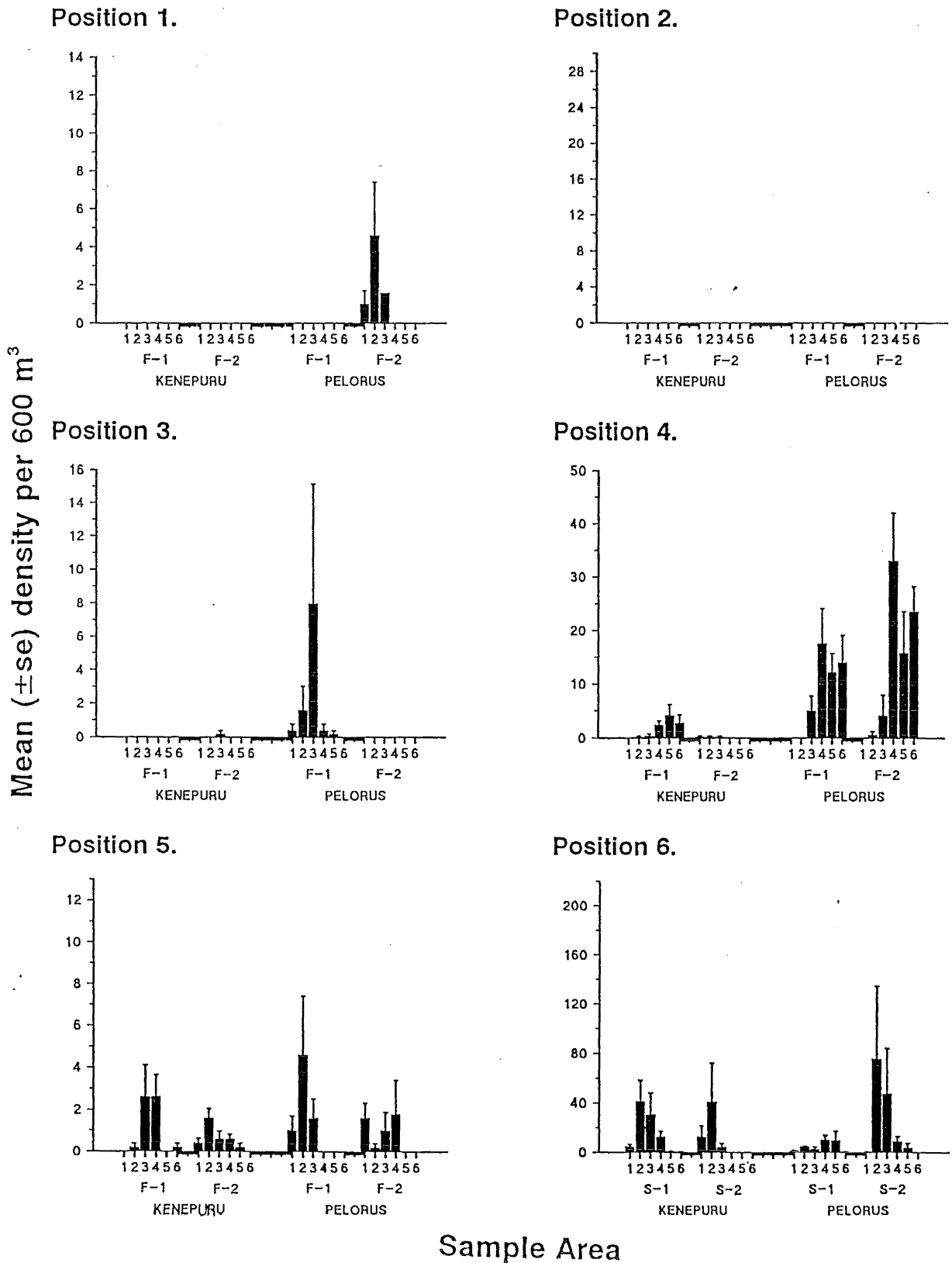


Figure 3.11: Spring (1992) mean ( $\pm$ se) size classes of juvenile *Notolabrus celidotus* (<120 mm SL) observed in the six sampled positions. Sample positions were  $(n=5)$ : position 1=top 4 m droppers; position 2=bottom 4 m droppers; position 3=benthos below droppers; position 4=mooring block and benthos below mooring rope; position 5=mooring rope; position 6=adjacent subtidal zones  $(n=3)$ . Size classes (SL) are: 1=0-20 mm, 2=21-40 mm, 3=41-60 mm, 4=61-80 mm, 5=81-100 mm, 6=101-120 mm.

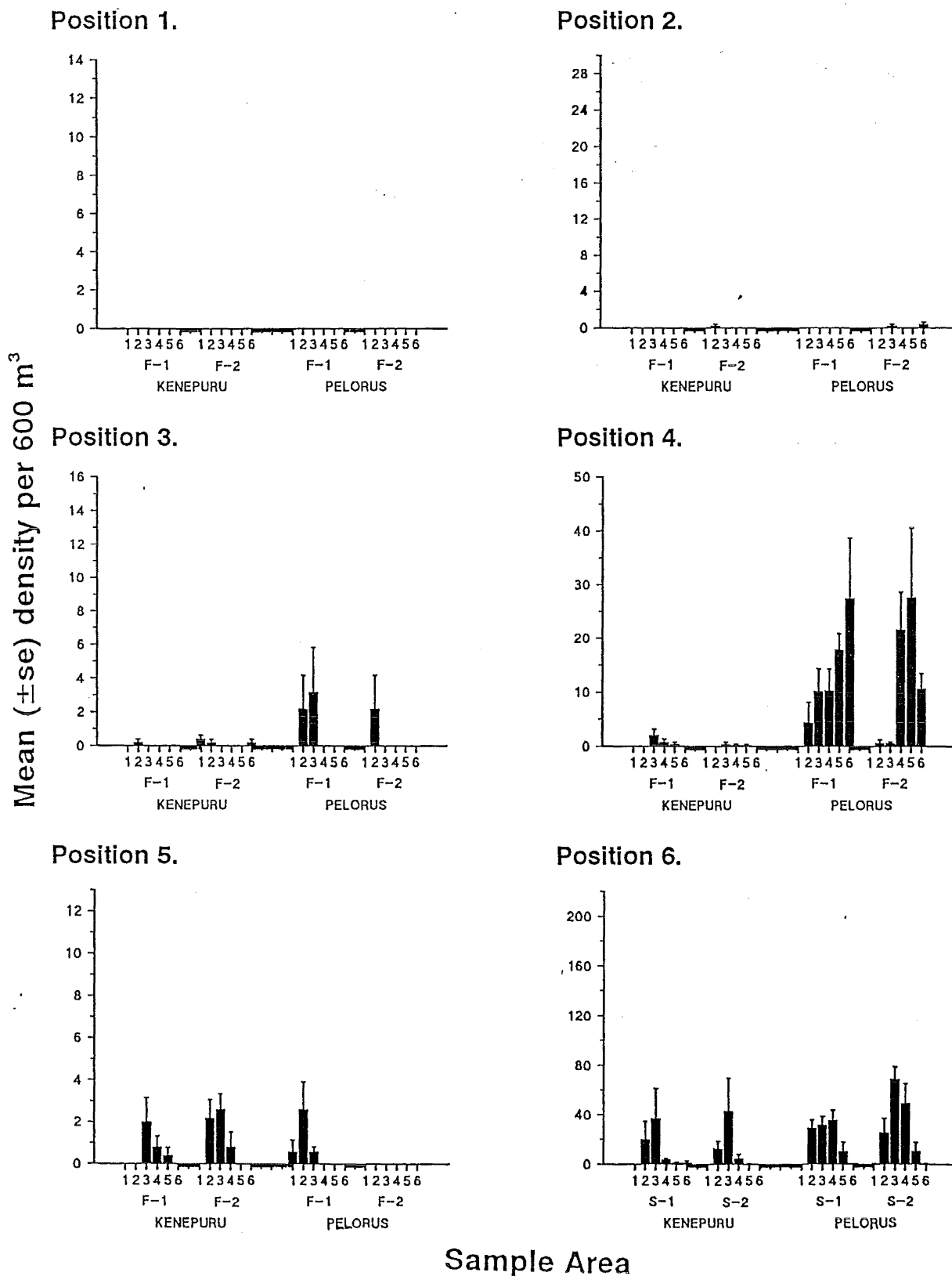
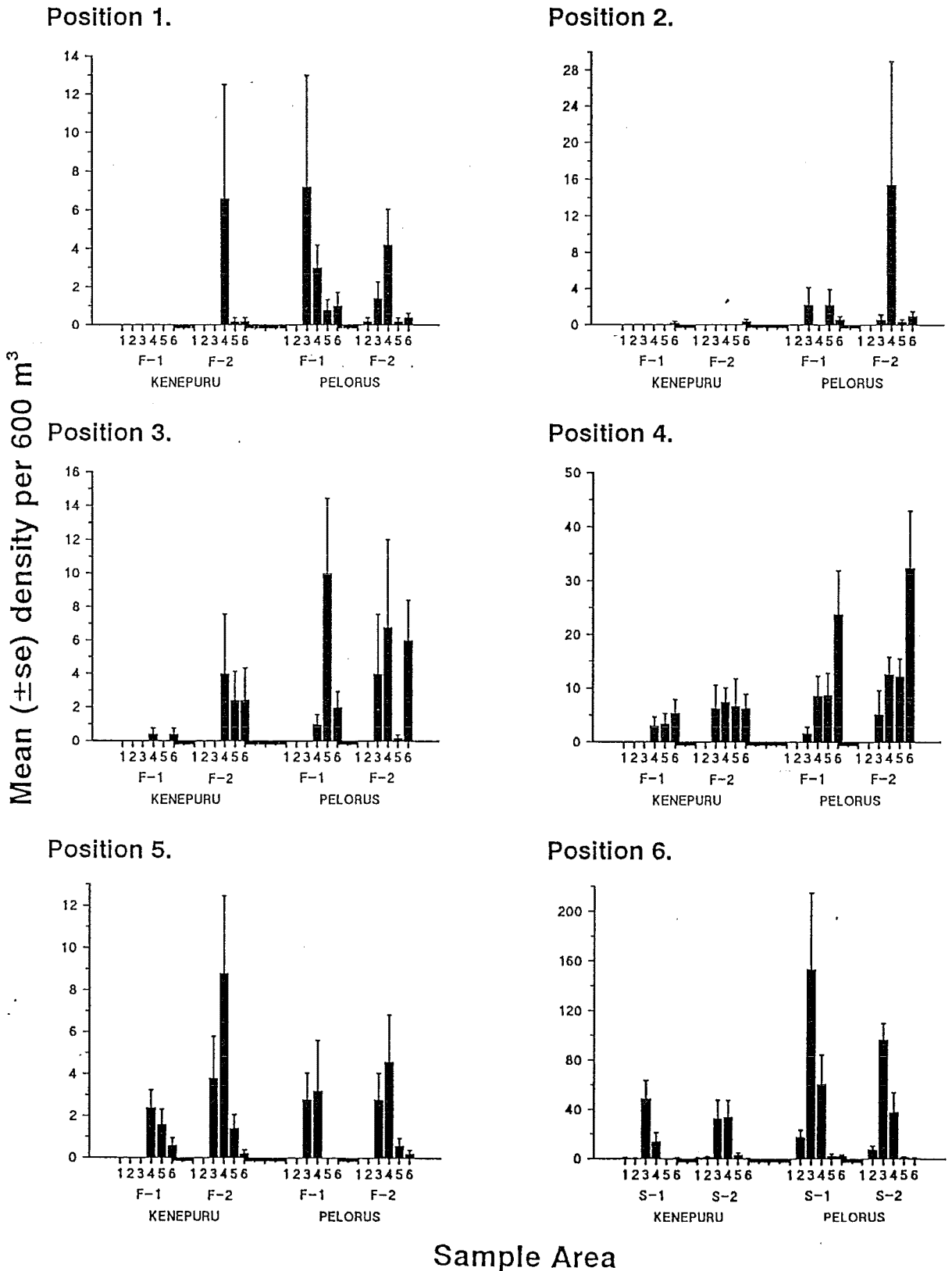


Figure 3.12: Summer (1992) mean ( $\pm$ se) size classes of juvenile *Notolabrus celidotus* (<120 mm SL) observed in the six sampled positions. Sample positions were ( $n=5$ ): position 1=top 4 m droppers; position 2=bottom 4 m droppers; position 3=benthos below droppers; position 4=mooring block and benthos below mooring rope; position 5=mooring rope; position 6=adjacent subtidal zones ( $n=3$ ). Size classes (SL) are: 1=0-20 mm, 2=21-40 mm, 3=41-60 mm, 4=61-80 mm, 5=81-100 mm, 6=101-120 mm.





### 3.4 DISCUSSION

The abundances and distributions of juvenile *Notolabrus celidotus* (<120 mm SL) associated with mussel farms have been described for areas of both Kenepuru and Pelorus Sounds. Although some details of adult *N. celidotus* observed in this survey are also examined here and in Chapter Four (Table 4.1), more specific details are given by Clarke (1993).

The densities of both juvenile and adult *N. celidotus* were significantly higher in sites (farms) of Pelorus Sound than those in Kenepuru Sound. Juvenile densities were approximately twice as high in Pelorus than in Kenepuru Sound (Figures 3.5 and 3.6). This pattern remained relatively stable between bays and farms of each sound. However, there was considerable variation in the densities of juvenile *N. celidotus* between the transect areas of each mussel farm (Figure 3.5).

Observations within specific areas associated with each mussel farms showed that most of the juvenile *N. celidotus* were located mainly in natural subtidal areas surveyed adjacent to each sampled mussel farm (Figure 3.6). The only other area with comparable densities was the mooring blocks and associated benthos of each farm (Figure 3.6). Although the numbers of fish observed on the suspended structures of mussel farms did increase slightly over summer, these always had comparatively lower densities than on mooring blocks or in adjacent natural subtidal areas (Figure 3.6).

The natural subtidal areas sampled were characterised by shallow depth (<6 m) and a rocky/stony benthos irregularly covered in patches of macro-algae, particularly *Cystophora scalaris* (Plate 3.6). Mooring blocks, on the other hand, were always deeper (>8 m), on a muddier/sandier substrate and virtually devoid of macro-algal cover (Plates 3.4). An analysis of size classes observed in these areas showed that populations of *N. celidotus* on mooring blocks were very different from those in natural subtidal areas and among suspended structures of mussel farms (Figures 3.9-3.12). *N. celidotus* around mooring blocks were dominated by fish greater than 80mm (SL) whereas those in shallower areas, especially adjacent natural subtidal areas, were dominated by fish less than 80mm (SL). Within this size grouping, newly recruited fish (<20mm SL) were observed almost exclusively in natural subtidal areas, although small numbers were seen

in the more profuse encrusting organisms growing on the mooring ropes of mussel farms in Pelorus Sound (Figure 3.8 and Plate 3.5).

Although total densities of *N. celidotus* were up to eight times greater in this study, Jones (1984a and 1984b) observed similar depth related patterns in the distribution of juvenile *N. celidotus* in coastal areas near Leigh. In both this and Jones' studies, small juveniles were aggregated in loose groupings in natural subtidal areas (Jones, 1984a and 1984b) whereas older fish were more dispersed in deeper and more open water (Jones, 1984c; Clarke, 1993).

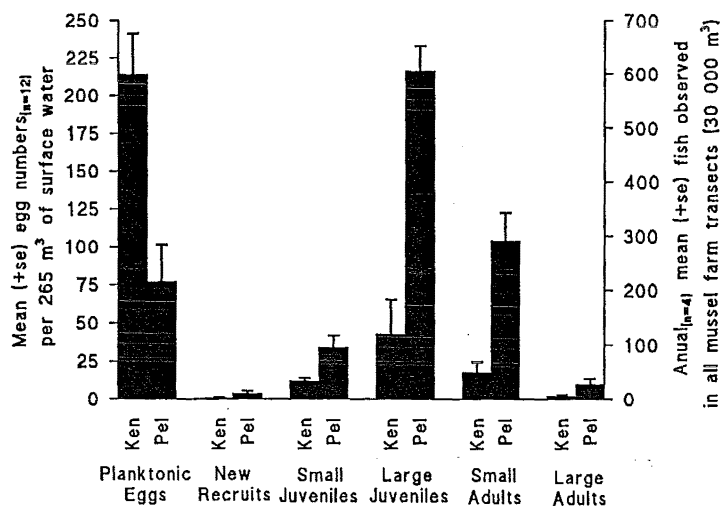
The general pattern described in Jones' five year study (Jones, 1981a) was that *N. celidotus* recruit into the macro-algae of shallow areas and then move into deeper, more open water as they mature (Jones, 1984a and 1984b). Coinciding with these events Jones also observed changes in the diet of *N. celidotus* (Jones, 1984a). Small fish (<50 mm SL) fed in small groups, taking mainly gammarid amphipods and copepods from among the fronds of macro-algae. With increasing size, however, juvenile *N. celidotus* switched to feeding on rocky substrate so that amphipods and isopods formed 90% of the diet of fish between 50 and 110 mm (SL). Adult fish between the sizes of 110 and 180 mm (SL) fed increasingly on crabs, ophiuroids, bivalves and hermit crabs. Large adults (>180 mm) fed mainly on large bivalves, gastropods and hermit crabs. These dietary size groupings (described in Thompson and Jones, 1983) have been used here to divide the *N. celidotus* observed in all transect areas of mussel farms (Figure 3.13) and natural subtidal areas (Figure 3.14) of the seasonal survey of 1993. These results have been used to observe the relative densities of these fish on mussel farms and in natural subtidal areas as they grow. A stationary age distribution has been assumed on the basis of Jones' (1981a, 1984b and 1984c) finding of consistent yearly recruitment among North Island populations of *N. celidotus*.

From these results it appears that the same migration described by Jones (1984a, 1984b and 1984c) occurred in populations of *N. celidotus* associated with mussel farms in the Marlborough Sounds. Recruitment of these fish occurred mainly into natural subtidal areas (Figure 3.14) over late summer and early autumn (Figure 3.8). *N. celidotus* appear to develop there as juveniles (Figure 3.14). As their diet changes to

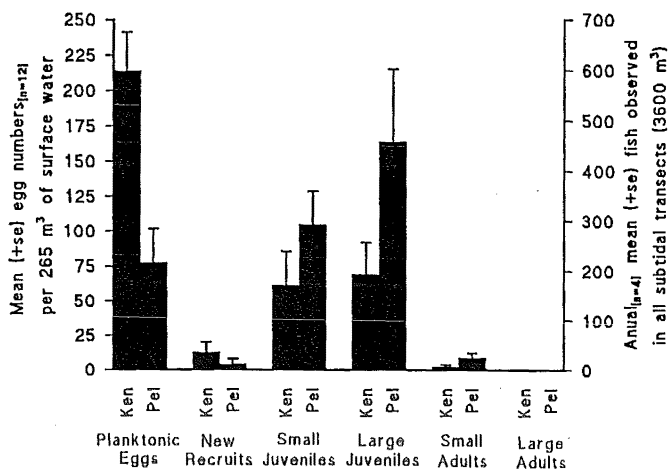
prey found predominately in more open areas, larger juveniles (50-100 mm SL) appear to start migrating onto mussel farms (aggregating mainly around mooring blocks) (Figure 3.13). By the time they reach adulthood *N. celidotus* are almost exclusively found in the deeper water around mussel farms (Figure 3.14). Jones (1981a) observed that this movement into deeper water occurred in the first, second or third year, depending on the growth rate in each area. Ideally, a tagging programme in natural subtidal areas could have confirmed this event for *N. celidotus* observed in this study, but unfortunately all efforts to capture fish alive failed.

**Figure 3.13:** Mean ( $\pm$  se) densities of static life history phases observed on mussel farms (transects 1-5) and in adjacent natural subtidal areas. Reef phase groupings are divided by standard length on the basis of diet as defined by Thompson and Jones (1983). New recruits, <20 mm; small juveniles, 20-50 mm; large juveniles, 51-110 mm; small adults, 111-180 mm; large adults, >180 mm.

**Mussel Farms**



**Adjacent Natural Areas**



Significant correlations with specific habitat covariates have been observed among the abundance patterns of many New Zealand reef fish (Table 2 in Jones, 1988). For example, the density patterns of large *N. celidotus* are known to correlate with topographic complexity (Jones, 1984c). This phenomenon was also observed in this study as large juveniles and adults were closely associated with the vertical relief provided by the mooring blocks of mussel farms (Plate 3.3). This is discussed by Clarke (1993). By comparison, the abundance patterns of juvenile *N. celidotus*, like many other juvenile reef fish, have been significantly correlated with macro-algal cover (Jones, 1984b).

Jones (1984a and 1984b) observed that juvenile *N. celidotus* were closely associated with shallow macro-algae. During settlement, recruitment and subsequent development, macro-algae apparently serves as a larder in which these fish can feed on micro-crustaceans taken from the macro-algal fronds (Jones, 1984a; Taylor, 1991). However, Jones (1984a) implied that the importance of macro-algae was more a factor of shelter than of food since higher densities newly recruited *N. celidotus* prey items (gammarid amphipods) were found in more open habitats where these fish would be vulnerable to predation (Jones, 1984a). Small *N. celidotus*, less than 25 mm fork length, consistently consume mostly benthic copepods picked from the fronds of macro-algae. Yet at sizes beyond this, the primary importance of shelter is further suggested by observations of 0+ year class fish aggregated in macro-algae (above 100 per 500m<sup>2</sup><sup>1</sup>) foraging mainly on plankton rather than the small crustaceans associated with the macro-algae (Jones, 1983). Fish observed in natural subtidal areas of this survey were always at densities where planktonic food is expected to be most important (Figure 3.6). Behavioral observations of *N. celidotus*<sub>(n=50)</sub> done on an ad hoc basis tended to confirm that juveniles (30-100 mm SL) in this survey fed mainly from the plankton.

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<sup>1</sup> Densities of *N. celidotus* observed by Jones (1983) are quoted per 50x10 m two dimensional transect. Consequently in this study, where transects are measured as volumes (30x5x4 m), 100 fish per 500 m<sup>2</sup> equates to 30 fish per 600 m<sup>3</sup>.

The abundance of macro-algae observed in natural subtidal areas of this study varied greatly between transects. This probably accounted for some of the spatial variation observed in the densities of juvenile *N. celidotus* in these areas. Densities of juvenile *N. celidotus* and macro-algal cover were also significantly influenced by many of the same factors in their respective ANOVAs (Tables 3.3 and 3.4). A significant correlation between these two factors further supports that a similar relationship to that described by Jones (1984a and 1984b) exists between macro-algae and juvenile *N. celidotus* in mussel farms of the Marlborough Sounds. Interestingly, macro-algal coverage (Figure 3.7) was significantly greater in the natural subtidal areas of sites in Pelorus Sound than in Kenepuru Sound (Tables 3.2, 3.3 and 3.4). This is possibly the result of low levels of light penetration (Bradford *et al*, 1987), lack of suitable substrate in Kenepuru Sound and siltration.

Because Jones (1984b) experimentally showed a cause and effect relationship between densities of macro-algae and the abundance levels of juvenile *N. celidotus*, it is possible that the lower levels of macro-algae observed in Kenepuru Sound are indirectly responsible for the lower numbers of *N. celidotus* observed there.

Interestingly, some newly recruited *N. celidotus* were also observed among the encrusting sessile invertebrates and macro-algae on mooring ropes of mussel farms (Figure 3.8). This suggests that these assemblages may function like macro-algae in natural subtidal areas by facilitating a small amount of recruitment directly into the structures of mussel farms. This hypothesis is further investigated in Chapter Five. Oddly, however, newly recruited *N. celidotus* were seldom observed in the moderately macro-algal cloaked dropper lines of mussel farms (Plate 3.1). Interspecific interactions between fishes after settlement can affect the spatial distributions of reef fish (Ebersole, 1985; Robertson and Gaines, 1986). More specifically, Thompson and Jones (1983) showed that blennioid fish *Forsterygion varium* actively seek to exclude *N. celidotus* from small 1 to 2 m<sup>2</sup> territories. This behaviour apparently functions both to defend nests and preserve the food supply of *F. varium* (Thompson and Jones, 1983). Aggressive interspecific interactions with the many adult *F. varium* resident on dropper lines were observed on an ad hoc basis. These may have retarded newly settled *N. celidotus* from

recruiting into this area. This hypothesis is supported by observations of *F. varium* occurring predominantly on the dropper lines of mussel farms and not the mooring ropes.

In this study, ecological factors explaining most of the variation observed in the densities of juvenile *N. celidotus* within the mussel farm environment have been identified on a number of temporal and spatial scales (Tables 3.2 and 3.3). Of these, densities varied notably more between habitat types (transect locations) than between variations of any other factor investigated. However, differences between densities in each large scale regional locations (between sounds) were not always attributed to spatial variations in levels of recruitment as Jones observed among populations of *N. celidotus* in the North Island (Jones, 1984b and 1984c).

The abundance patterns of juvenile and adult *N. celidotus* observed in Kenepuru and Pelorus Sounds were the reverse of planktonic *N. celidotus* egg abundances described in Chapter Two (Figure 3.13 and 3.14). Although both these observations were static in terms of the *N. celidotus* life cycle of about 7yrs (Jones, 1980), they suggest that in Kenepuru Sound some process limits the abundance of *N. celidotus* between the pelagic and reef associated stages of life. Because the abundance patterns of newly recruited *N. celidotus* (Figure 3.14) were more like those of planktonic eggs than juvenile and adult fish it further seems that this process occurs after settlement and recruitment has occurred.

Observations made in Chapter Two suggested that large numbers of planktonic *N. celidotus* eggs, and apparently also new recruits, build up in Kenepuru Sound mainly as the result of hydrological processes operating in the pelagic environment. However, the effect of these hydrological processes are not reflected in the densities of juvenile and adult *N. celidotus* observed in Kenepuru Sound when compared to the larger numbers observed in Pelorus Sound where eggs and new recruits were less dense (Figures 3.13 and 3.14). This result is a paradox in the Non-equilibrium hypothesis (Doherty, 1983) since, in Kenepuru Sound, the observed *N. celidotus* populations do not appear to be regulated by the availability of individuals recruited from the plankton.

## CHAPTER FOUR

### MORPHOMETRIC RELATIONSHIPS, GROWTH, AGE-CLASS DISTRIBUTION AND SPAWNING

#### 4.1 INTRODUCTION

Histology and morphology allow an examination of *in vivo* processes that help to explain processes observed in the external environment. Detailed histological and morphological investigations have been done for populations of *Notolabrus celidotus* in the North Island at locations in both Wellington (Choat, 1965; Todd, 1969; Jones, 1980) and Leigh (Jones, 1980). One aim of this chapter is to make similar observations of *N. celidotus* on mussel farms of the Marlborough Sounds.

Growth as a measure of competitive interaction in reef fish communities has received particular attention recently (Jones and Norman, 1986; Jones, 1986, 1987a, 1987b and 1988). In a manipulative feeding experiment, Jones (1986) showed that increasing the amount of food delivered to patch-reefs readily improved the growth of local damselfish, *Pomacentrus amboinensis*. In a complementary experiment, Jones (1987) also showed that the major effect of increasing densities of *P. amboinensis* was to retard growth, rather than to induce mortality. Both of these experiments suggest that flexibilities in the growth rates of reef fish can mask competitive interactions for food if competition is measured in terms of mortality. Jones' experiments (Jones, 1986 and 1987) also questioned traditional concepts of 'carrying capacity' (Doherty, 1983) since they showed that in terms of growth, food becomes the object of competitive interactions at densities below those experiencing mortality.

In Chapter Three, it was shown that densities of juvenile (<120mm SL) *N. celidotus* on mussel farms and in adjacent natural subtidal areas were greater in Pelorus Sound than in Kenepuru Sound. Analysis of similar data collected on 'adult' fish (>120mm) is given in Clarke (1993). In this chapter, the aim was to determine age/size relationships of *N. celidotus* on mussel farms near those studied in Chapter Three (Figure 1.1.). This would then allow age-class distributions to be deduced from transect data by analyzing size classes.

The basic attribute of growth is a change in mass over time. Hence, to estimate population growth rates from static samples, each fish has to be accurately assigned a measure of age. A variety of methods are available for determining the age of fish. In this study, scales were used to age *N. celidotus* since this is considered a superior method of aging from opercular and otolith bones for this species (Todd, 1969; Jones, 1980). The basis of age determination by means of scales rests on the assumption that a ring (annulus) is formed each year (Rosa and Lee, 1920). Jones (1980) confirmed this for *N. celidotus* at the marine reserve near Leigh, showing that annuli were laid down in November of each year.

To estimate the time and duration of spawning, gonad weights can be used as an indicator of changes in gonad ripeness (West, 1990). Such methods rest on the assumption that a spent or immature gonad is small and a ripe gonad is large; consequently, a sudden decrease in gonad weight can indicate that spawning has occurred (Giese, 1958). In this part of the study, gonad weights were used to identify periods of peak spawning for *N. celidotus* around mussel farms in the Marlborough Sounds.

This study quantifies inter-relationships of size, age, colour phase, total body weight and gonad weight in samples of *N. celidotus* taken from two mussel farms; one in Kenepuru Sound and one in Pelorus Sound. Aspects of growth, age-class densities and spawning were then compared to a similar study done in the North Island (Jones, 1980).

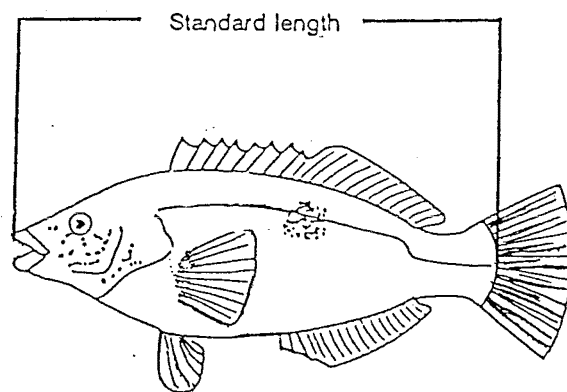


## 4.2 MATERIALS AND METHODS

*N. celidotus* were either speared or hooked by line near the mooring blocks of mussel farms in Kenepuru Sound (Waitaria Bay) and Pelorus Sound (Otatara Bay) (Figure 1.1). Collecting began in February 1991, and 25 samples were taken at approximately monthly intervals until January 1993. Each sample consisted of about 30 fish between 60 mm and 230 mm SL. In all, 613 fish were examined. Most were processed fresh, but on occasion samples were preserved in 10% formalin for short periods of time.

The colour phase of each fish was visually determined as either initial or terminal phase. Because this study lacked the backing of histological determination of sex through the use of sectioned gonads (yet to be examined), transitional phase fish were not recorded. This was because simple visual examinations could only detect gross sexual differences. Each fish was then weighed to the nearest gram, the standard length measured to the nearest millimetre (Figure 4.1) and the gonad removed and weighed to  $\pm 0.001$  gram.

Figure 4.1.: The standard length is the distance from the tip of the nose to the terminal vertebra.



Three primary scales were taken from behind the left pectoral fin for use in estimating the age of each fish. Replacement scales were discarded. Primary scales were viewed under a low power microscope, the annuli counted and the mode recorded. Counts from the same fish were usually consistent.

Morphometric relationships were examined for fish caught in each sound by plotting the mean standard length ( $\pm$  se) and weight of each colour phase against each age group. Growth was then compared between study areas by performing one-way ANOVAs on the standard lengths and weights of equivalent year-classes in each area.

Length-weight relationships were plotted for each colour phase in both study areas and regression lines were fitted (Minitab, release 8.2). Statistical comparisons between regression lines were then made using analysis of covariance (ANCOVA) to determine if relationships between these variables differed between colour phases and study areas (Ricker, 1973). However, before comparisons were made, tests for homogeneity of variances between regression lines were done using the ratio of Mean Square values as an F-value. Provided no significant difference between regression variances was observed, tests for equal slopes and adjusted means were done (Snedecor and Cochran, 1967).

As outlined in Chapter Three (Section 3.2.4), visual estimates of *N. celidotus* were made on mussel farms in Kenepuru Sound (Schnapper Point) and Pelorus Sound (Elie Bay) (Figure 1.1). Using the size ranges of each age class, deduced from the age/length curves of fish sampled in Kenepuru Sound (Waitaria Bay) and Pelorus Sound (Otatarā Bay), fish observed in each area were then arranged into age groupings based on their standard lengths. In both these areas, individual age classes remained reasonably discrete for the first five years so that five separate age categories (0+, 1+, 2+, 3+, 4+ and  $\geq 5+$ ) could be recognised for initial-phase female fish.

Periods of peak spawning activity were identified by plotting monthly mean gonad weights ( $\pm$  se) for initial-phase females and terminal-phase males from Kenepuru and Pelorus Sounds combined (Jones, 1980; Webb and Kingsford, 1992). Gonad weights were not plotted for each individual area as samples were taken from each of the two areas alternately. Therefore, periods of peak spawning activity are more representative of the entire study area.

## 4.3 RESULTS

### 4.3.1 Growth

Juvenile *N. celidotus* (0+ year class) caught in Kenepuru Sound were of similar size and weight to those caught in Pelorus Sound; however, numbers were too small for statistical comparisons (Figure 4.2c and 4.2d). In the 1+ year class, the mean standard length of *N. celidotus* in Kenepuru Sound ( $110 \pm 13.39$  mm) was significantly larger than that of fish in Pelorus Sound ( $92.5 \pm 3.96$  mm) (Figure 4.2c and 4.2d). This suggests that during the first year of life, *N. celidotus* sampled in Kenepuru Sound grew faster, as measured by length, than those taken from Pelorus Sound. One-way ANOVAs comparing the standard length data of selected year classes were done between sounds. These were significantly different at the 1% level for initial-phase female fish of the 2+ and 4+ year classes and for terminal-phase male fish of the 3+ and 5+ year classes. Females older than 5 years and males over 6 years in each sampled area did not have significantly different lengths. Considerable differences, therefore, exist between the growth rates (length/age relationships) of young adult *N. celidotus* sampled at the two locations in this study. Fish in Kenepuru Sound evidently grow faster up until the fifth (females) and sixth (males) years when their counterparts in Pelorus Sound catch up (Figure 4.2c and 4.2d), perhaps as a result of the changing dietary requirements of these fish as they grow (Jones, 1984a).

Age/length curves for Kenepuru Sound were similar to those for *N. celidotus* populations near the University of Auckland's Marine Laboratory at Leigh (Jones, 1980) (Figure 4.2a). Although *N. celidotus* in Kenepuru Sound were slower at reaching the 3+ year class, they then grew slightly faster than fish at Leigh (Figure 4.2a and 4.2c). *N. celidotus* caught in Pelorus Sound initially grew much slower than their counterparts at Leigh, but had caught up by the 4+ year class (Figure 4.2d). Interestingly, the mean lengths of terminal-phase fish in the Marlborough Sounds, especially in Kenepuru Sound, were larger than those of terminal-phase fish caught at Leigh.

Compared to fish in this study, *N. celidotus* caught less than 100 km east, in Island Bay, near Victoria University Marine Laboratory in Wellington (Jones, 1980),

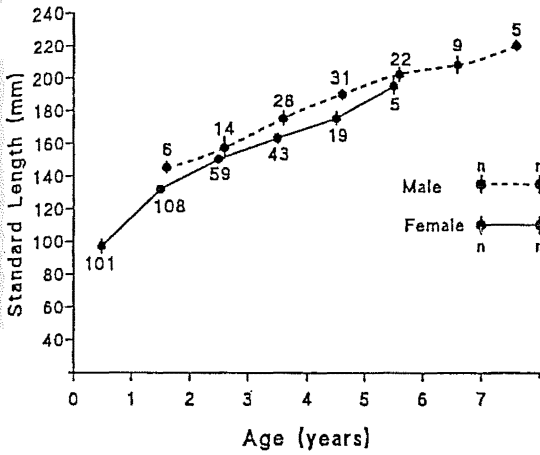
appear to grow substantially slower (Figure 4.2b). By comparison *N. celidotus* in Wellington appear to be a dwarf population.

One-way ANOVAs done on the weight data of selected year classes of each colour phase between Kenepuru and Pelorus Sounds were also significantly different at the 1% level for male fish up to the 3+ and 4+ year classes. However, no selected year class of female weights differed significantly between study areas, probably due to the smaller magnitude of weight increases with length in female fish (Figures 4.3a and 4.4a).

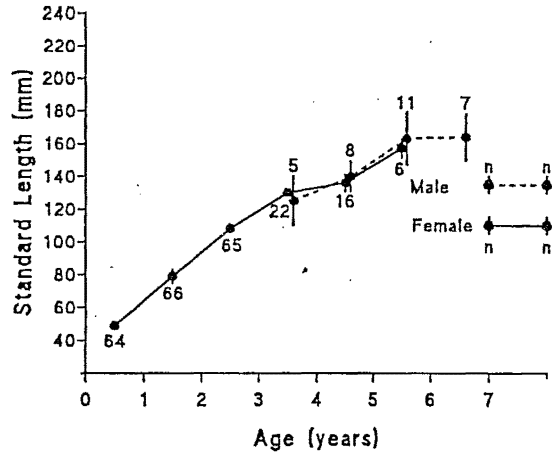
Relationships between length and weight appeared to differ between the colour phases, but not markedly between study areas in the Marlborough Sounds (Figures 4.3 and 4.4). Regression lines with variables log transformed (Ricker, 1973), were tested for homogenous variances. These were significantly different between sexes ( $F_{(93,93)}=43.16$ ,  $P<0.001$ ) and between study areas for both males ( $F_{(46,46)}=1.97$ ,  $p<0.05$ ) and females ( $F_{(141,141)}=1.968$ ,  $P<0.001$ ). Consequently, slopes and adjusted means were not compared.

Figure 4.2: Growth of *N. celidotus* measured by age versus mean standard length at: A) Leigh; B) Wellington; C) Kenepuru Sound; D) Pelorus Sound. Graphs of *N. celidotus* growth at Leigh and Wellington are reproduced from Figure 10 in Jones, 1980. Growth of *N. celidotus* measured by age versus mean weight is shown for: E) Kenepuru Sound (Waitaria Bay); F) Pelorus Sound (Otataru Bay). Sample size is indicated by 'n' and standard errors are shown. The mean age of 'X+' class fish is assumed to be 'X.5', males are displaced to the right.

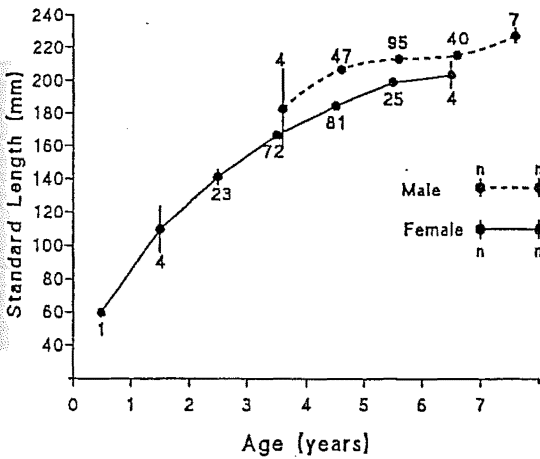
**A Leigh (near Auck Uni Marine Lab)**



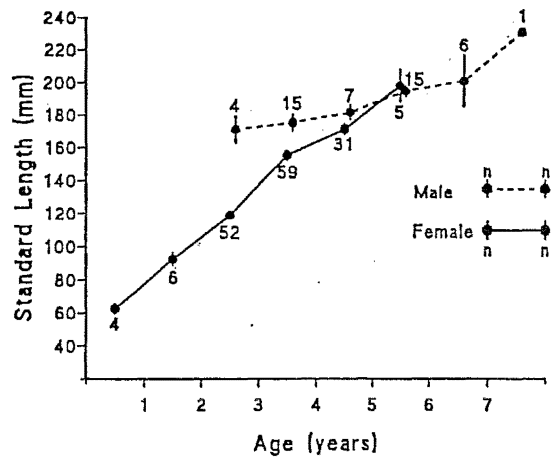
**B Wellington (Island Bay)**



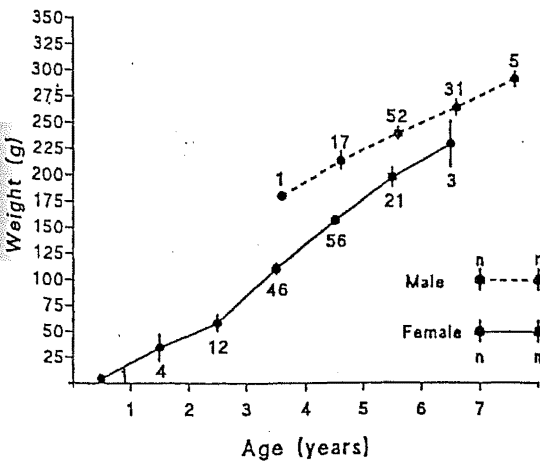
**C Kenepuru Sound (Waitaria Bay)**



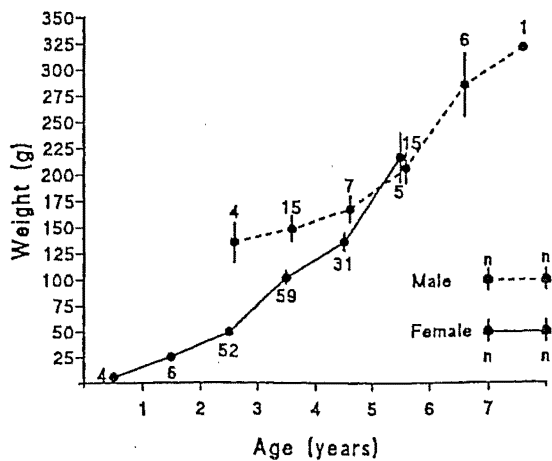
**D Pelorus Sound (Otataru Bay)**



**E Kenepuru Sound (Waitaria Bay)**



**F Pelorus Sound (Otataru Bay)**



**Figure 4.3:** Length-weight relationships of *N. celidotus* caught in Kenepuru Sound (Waitaria Bay).

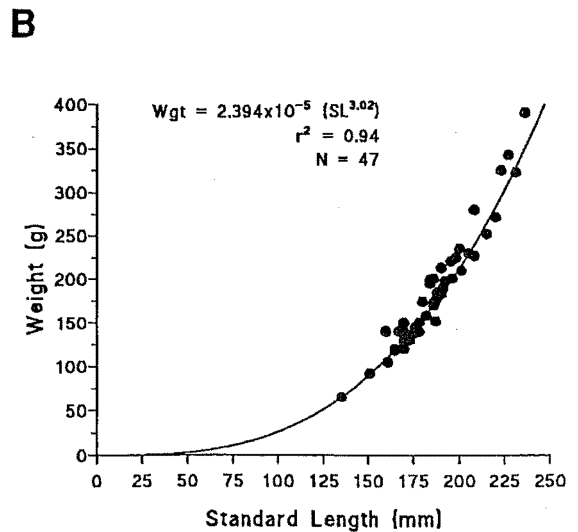
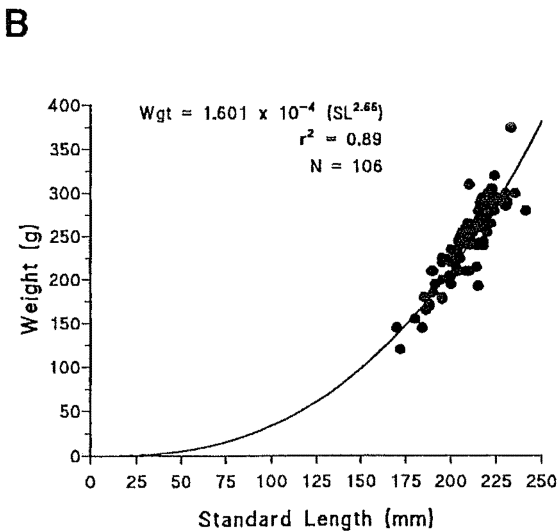
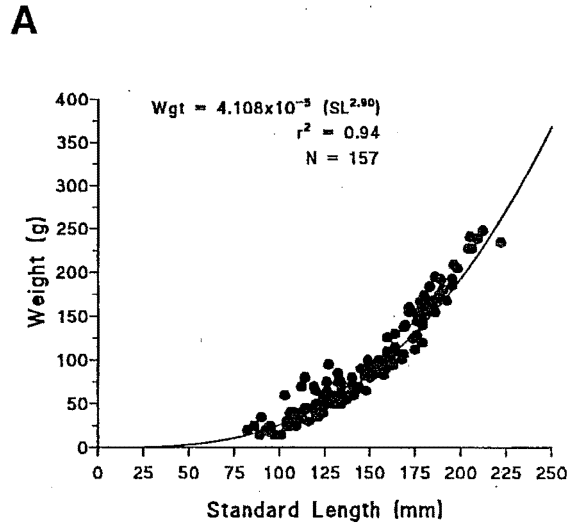
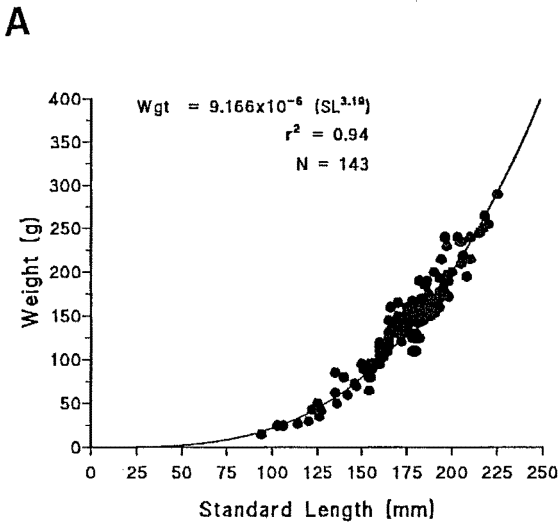
- (A) Female fish
- (B) Male fish

Linear regression equations are shown.

**Figure 4.4:** Length-weight relationships of *N. celidotus* caught in Pelorus Sound (Otatarā Bay).

- (A) Female fish
- (B) Male fish

Linear regression equations are shown.



### 4.3.2 Age class distribution and abundance

In Chapter Three it was shown that densities of small (<120mm SL) *N. celidotus*, both in mussel farms and adjacent natural subtidal areas, were greater in Pelorus Sound than in Kenepuru Sound (Figure 3.6). This result is amplified here along with more specific measures of adult density (Table 4.1). Size data from visual transects of the seasonal survey (outlined in Chapter Three) was sorted into age groups (read off figures 4.2c and 4.2d). Grouping the data in this way has clarified a number of other trends observed in Chapter Three. Mainly, *N. celidotus* populations observed in Kenepuru and Pelorus Sounds have a clear trend of juveniles (0+ year class) densely aggregating in shallow natural subtidal areas (Table 4.1). This is also evident in Jones' earlier observations in the North Island (Jones, 1980) although densities are up to eight times greater than in his study (Table 4.1). Older fish ( $\geq 1+$  year class) observed in this study were found predominantly in deeper water (8-20 m), near mooring blocks and beneath mussel farm dropper lines (Table 4.1). They were seldom seen on the actual structures of mussel farms suspended from the surface to the mid-depth range (Table 4.1). By comparison, Jones (1980) observed relatively high densities of *N. celidotus* ( $\geq 1+$  year class) in natural reef areas at the mid-depth range (Table 4.1). The total densities of fish observed by Jones (1980) in the middle-depth range at both Wellington and Leigh were similar to the densities of fish observed on the structures of mussel farms in Kenepuru and Pelorus Sounds, but juveniles (0+ year class) made up comparatively more of the densities observed on mussel farms (Table 4.1).

The densities of *N. celidotus* under mussel farms (8-20m) were higher than those observed by Jones (1980) in transects at comparable depths (9-12 m) at Wellington and Leigh. In Pelorus Sound, *N. celidotus* were particularly abundant under mussel farms (Table 4.1).

In both this study and in Jones' (1980), shallow areas (1-6m) showed noticeable losses in densities of juvenile *N. celidotus* moving into the 1+ year-class, except at Leigh in 1977 (Table 4.1). At the same stage of development, fish in deeper areas (other than those around the suspended structures of mussel farms) also show a subsequent increase in the 1+ year-class (Table 4.1).

These results indicate that, in general, *N. celidotus* recruit into shallow areas and then move into deeper water as they mature (Jones, 1984b). However, fish observed

on the actual structures of mussel farms suspended in the mid-depth range (particularly mooring ropes, Figure 3.7) also had noticeable losses in densities of juvenile fish moving into the 1+ year-class (Table 4.1). It appears that some *N. celidotus* also recruit and develop in these structures.

Static survivorship curves can be calculated from age-specific density estimates, provided a stationary age distribution can be assumed. Jones' (1981a, 1984b and 1984c) finding of consistent recruitment among years for different habitats lends support to this assumption. In Figure 4.5, the number of initial-phase female fish of each year-class observed in all transects has been used to construct a static survivorship curve for *N. celidotus* in Kenepuru and Pelorus Sounds by determining each sequential year-class proportion of the 0+ year-class. Both curves are characteristic of populations with high reproductive rates and heavy mortality in the early stages (Solomon, 1969). However, mortality is much heavier during the 0+ year-class of *N. celidotus* in Kenepuru Sound (Figure 4.5). This is particularly evident in natural subtidal areas of Kenepuru Sound that, compared to Wellington and Leigh (Jones, 1980), have very high densities of the 0+ year-class but relatively low densities of 1+ year-class fish (Table 4.1).

**Figure 4.5:** Survivorship curves for Initial Phase *N. celidotus* observed in all transects done in Kenepuru Sound (Schnapper Pt) and Pelorus Sound (Elie Bay) during 1993. Age values were assigned based on standard length/age relationships of fish sampled in Waitaria Bay (Kenepuru Sound) and Otatara Bay (Pelorus Sound).

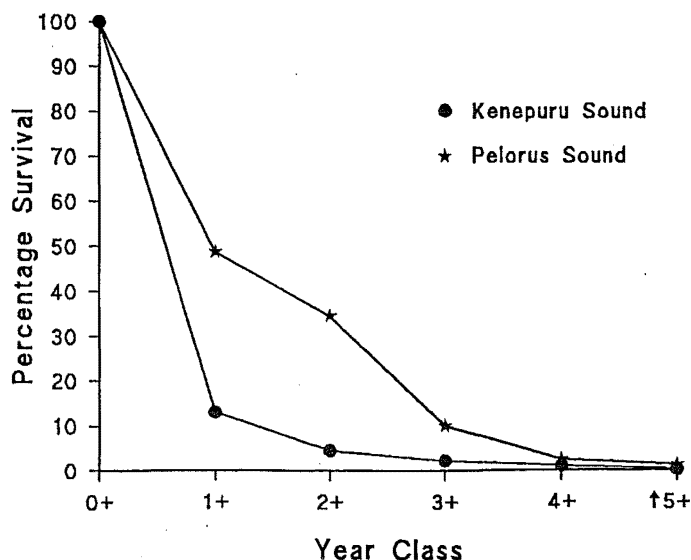




Table 4.1: Age specific density estimates (means  $\pm$  se) derived from census results of *N. celidotus* observed in 150m<sup>2</sup> transects, described in Chapter 3. The data from counts done in the North Island (Leigh and Wellington) is taken from surveys done by G.P. Jones during 1976 and 1977 (Table 2; Jones, 1980). The values shown here are standardised to 150m<sup>2</sup> transects for means and standard errors of Jones's observations using 50 x 10 m transects. Visual counts in the South Island (Kenepuru and Pelorus Sounds) were done seasonally during 1992. Transects were 30 x 5 m. Mean densities are given for each age and colour category per 150m<sup>2</sup>  $\pm$  standard errors at three depth ranges in each location.

Leigh Waterfall Reef, June 1976 and '77						
	Inner 2-6m		Mid 5-9m		Outer 9-12m	
	1976	1977	1976	1977	1976	1977
IP♀ 0+	3.9 $\pm$ 0.7	2.0 $\pm$ 0.5	1.0 $\pm$ 0.3	0.4 $\pm$ 0.2	0.1 $\pm$ 0.1	0.8 $\pm$ 0.3
≥1+	1.6 $\pm$ 0.3	3.1 $\pm$ 0.5	1.6 $\pm$ 0.2	2.3 $\pm$ 0.3	1.1 $\pm$ 0.3	1.1 $\pm$ 0.3
TP♂	0.4 $\pm$ 0.1	1.4 $\pm$ 0.2	1.8 $\pm$ 0.2	2.3 $\pm$ 0.4	0.7 $\pm$ 0.1	0.6 $\pm$ 0.2
Total	5.2 $\pm$ 0.8	6.5 $\pm$ 0.6	3.7 $\pm$ 1.6	5.0 $\pm$ 0.6	1.9 $\pm$ 0.3	2.5 $\pm$ 0.7

Wellington Owhiro Bay, February 1977			
	Ramp Pool 2-6m	Reef Edge 6-10m	Lone Rock 9-13m
	IP♀ 0+	14.3 $\pm$ 2.0	0.2 $\pm$ 0.1
1+	3.7 $\pm$ 2.9	1.3 $\pm$ 0.4	0.1 $\pm$ 0.1
2+	1.1 $\pm$ 0.4	2.8 $\pm$ 0.8	2.6 $\pm$ 1.7
≥3+	1.0 $\pm$ 0.2	1.1 $\pm$ 0.3	1.4 $\pm$ 0.5
TP♂	0.2 $\pm$ 0.1	0.5 $\pm$ 0.2	0.4 $\pm$ 0.2
Total	20.4 $\pm$ 1.9	5.9 $\pm$ 1.4	4.6 $\pm$ 1.4

Kenepuru Sound Schnapper Pt, Yearly average (n=4) 1992			
	Subtidal <sup>o1</sup> 1-6m	On Mussel Farms <sup>o2</sup> 0-10m	Below Mussel Farms <sup>o3</sup> 8-20m
	IP♀ 0+	68.52 $\pm$ 12.51	2.28 $\pm$ 0.63
1+	1.35 $\pm$ 0.34	0.34 $\pm$ 0.08	2.36 $\pm$ 0.07
2+	0.65 $\pm$ 0.19	0.13 $\pm$ 0.04	0.74 $\pm$ 0.02
3+	0.22 $\pm$ 0.09	0.09 $\pm$ 0.05	0.36 $\pm$ 0.01
4+	0.13 $\pm$ 0.10	0.02 $\pm$ 0.01	0.18 $\pm$ 0.01
≥5+	0	0	0.08 $\pm$ 0.01
TP♂	0	0.04 $\pm$ 0.02	0.20 $\pm$ 0.01
Total	70.87 $\pm$ 12.41	2.90 $\pm$ 0.68	5.81 $\pm$ 0.16

Pelorus Sound Otatara Bay, Yearly average (n=4) 1992			
	Subtidal <sup>o1</sup> 1-6m	On Mussel Farms <sup>o2</sup> 0-10m	Below Mussel Farms <sup>o3</sup> 8-20m
	IP♀ 0+	114.13 $\pm$ 20.28	2.86 $\pm$ 0.71
1+	17.22 $\pm$ 5.63	2.18 $\pm$ 0.62	14.00 $\pm$ 2.58
2+	0.78 $\pm$ 0.21	1.37 $\pm$ 0.41	13.58 $\pm$ 2.11
3+	0.13 $\pm$ 0.10	0.37 $\pm$ 0.15	4.01 $\pm$ 0.73
4+	0	0.09 $\pm$ 0.06	0.91 $\pm$ 0.16
≥5+	0	0.05 $\pm$ 0.04	0.47 $\pm$ 0.11
TP♂	2.22 $\pm$ 1.32	0.16 $\pm$ 0.08	0.74 $\pm$ 0.16
Total	134.48 $\pm$ 21.52	7.09 $\pm$ 1.29	41.41 $\pm$ 5.00

o1. Chapter 3.2.4, transect 6.

o2. Chapter 3.2.4, transects 1, 2 and 5.

o3. Chapter 3.2.4, transects 3 and 4.

### 4.3.3 Seasonal variations in gonad weight

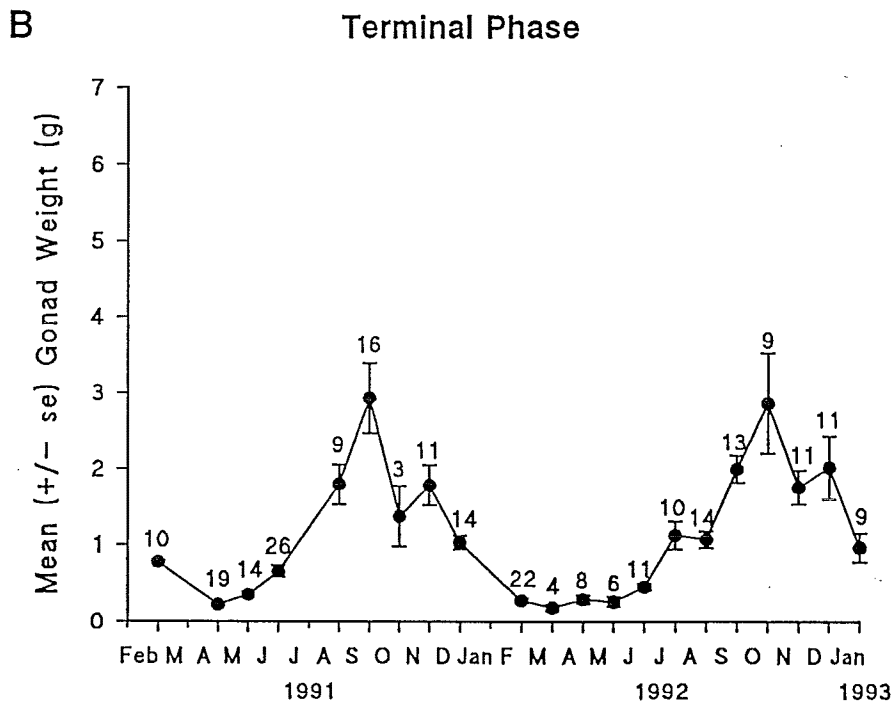
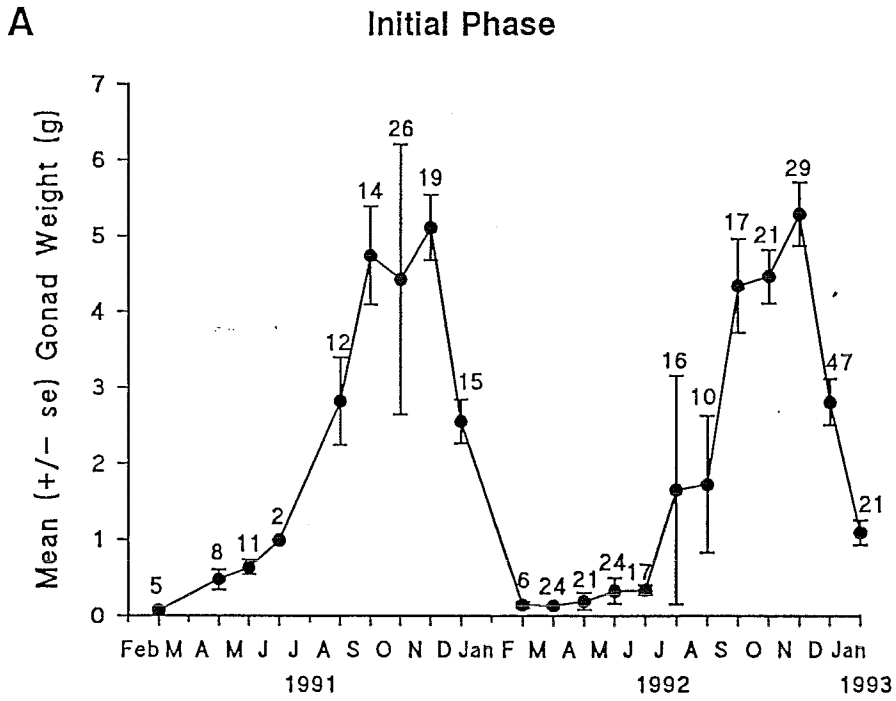
Seasonal variations in gonad weight were reasonably synchronised and consistent for both colour phases of *N. celidotus* over the two years sampled (Figures 4.6a and 4.6b). In both years, initial-phase female gonad weight increased markedly in August, remained high over September and October and peaked in November (Figure 4.6a). Female gonad weights then declined to their lowest level in February (1991) (Figure 4.6a).

Terminal-phase males showed an abrupt increase in gonad weight in August 1991 and September 1992 and peaks were reached in September 1991 and October 1992 (Figure 4.6b). After a small decline, however, gonad weights of terminal-phase males showed a second peak, which coincided with that of females in November 1991 (Figure 4.6b). Gonad weights of terminal-phase males declined to their lowest level in March 1991 (Figure 4.6b).

Gonad weights of *N. celidotus* taken at Leigh indicated that spawning took place mainly from August to November, but also occurred as late as December (Jones, 1980). These were confirmed by measures of gonad ripeness using sectioned gonad tissue from mature female fish (Jones, 1980). In comparison, the gonad weights of *N. celidotus* in Kenepuru and Pelorus Sounds do not reach a mass indicative of spawning until October (Figure 4.6). Spawning then appears to continue spasmodically until January (Figure 4.6). However, this will need to be confirmed by measures of gonad ripeness from sectioned gonad tissue collected throughout the period of this study.

Figure 4.6: Mean monthly gonad weight ( $\pm$ se) of *N. celidotus* taken from Kenepuru and Pelorus Sounds between February 1991 and January 1993. Sample sizes are shown above standard error bars.

- A) Initial phase females
- B) Terminal phase males



#### 4.4 DISCUSSION

Although comparing only two areas, annual estimates of natural *N. celidotus* densities made on and around mussel farms in Kenepuru and Pelorus Sounds (Table 4.1) were inversely related to static estimates of growth observed in fish sampled nearby (Figure 4.2c and 4.2d). In his experiments on the damselfish *Pomacentrus amboinensis*, Jones (1986 and 1987) found that increasing the quantity of food increased growth rates, whilst increasing densities of conspecifics retarded them. As these results would predict, observations of *N. celidotus* living at higher densities in Pelorus Sound were characterised by a significantly lower rate of growth (Figure 4.2c and 4.2d). This is especially true if 0+ year-class fish are ignored (Table 4.1). Because the diet of *N. celidotus* alters significantly as fish mature, it is unlikely that juvenile and adult fish compete for the same food items (Jones, 1984).

Static growth estimates from fish sampled and observed in Pelorus Sound were also lower than for *N. celidotus* sampled at Leigh (Figure 4.2a), where densities of  $\geq 1+$  year-class fish and growth rates were similar to those observed in Kenepuru Sound (Table 4.1). However, the pattern is upset by the comparatively slow growth rates of *N. celidotus* sampled in Wellington (Figure 4.2b). For although densities of  $\geq 1+$  year-class fish were higher in Wellington than at either Leigh or Kenepuru Sound, they were less than one seventh of those observed in Pelorus Sound (Table 4.1), where growth rates were noticeably higher (Fig 4.2b and 4.2d).

In yet another manipulative experiment, Jones and Norman (1986) found that artificially decreasing densities of the herbivorous reef fish *Parma victoriae* allowed remaining individuals to increase their territory size. However, rather than simply eating more, fish consumed proportionally higher amounts of preferred food items. Presumably, food can become the object of competition among reef fish when high densities of conspecifics force fish to feed primarily on lower quality food types that are not as readily transformed into growth of body tissue (Jones, 1986 and 1987; Jones and Norman, 1986). Based on these observations it is difficult to explain the magnitude of a population's growth rate solely in terms of the densities observed. Before any firm conclusions can be drawn, physiological data will be required on both the efficiency of *N. celidotus* at converting food into growth and the nutritional value of various food items

consumed in studied areas. However, it remains feasible that the faster growth of adult *N. celidotus* in Kenepuru Sound, as compared to those in Pelorus Sound and at Leigh, is due to the lower densities of conspecifics in the area.

In both this study and Jones (1980), shallow areas (1-6 m) had noticeable losses in the densities of juvenile fish moving into the 1+ year-class, while at the same time deeper areas had subsequent increases in the 1+ year-class (Table 4.1). In Kenepuru Sound, fish observed on suspended structures of mussel farms also showed noticeable losses in densities of juvenile fish moving into the 1+ year-class (Table 4.1). This result further supports conclusions made in Chapter Three; that is, *N. celidotus* recruit into macro-algae in mainly natural subtidal areas, but also on the suspended structures of mussel farms (Figure 3.12). Juveniles develop there and appear to migrate to more exposed areas under mussel farms once they mature.

In Kenepuru Sound, the density of juvenile *N. celidotus* reaching the 1+ year-class was only 15% of those in the 0+ year-class (Figure 4.6 and Table 4.2). In comparison with other locations, this is a particularly high mortality for *N. celidotus* (Table 4.1). Since over 94% of the 0+ year-class fish observed in Kenepuru Sound were found in natural subtidal areas adjacent to mussel farms (Table 4.1), presumably most of this early mortality occurs there.

In a study of fine-scale distribution and behaviour of *N. celidotus*, Jones (1984) observed that the distribution of 0+ year-class fish was not explained by the distribution of their main food items. Instead, 0+ year-class fish were more closely associated with the shelter provided by macro-algal (Jones, 1984). Jones (1980) then confirmed this association with a macro-algae removal and addition experiment. In Chapter Three, fine-scale observations (25 m<sup>2</sup>) of *N. celidotus* densities were also significantly correlated with recordings of macro-algal cover, suggesting that a similar association existed between macro-algal cover and juvenile *N. celidotus* in this study area. Jones (1984) also observed that 0+ year-class *N. celidotus* foraged through small home ranges associated with macro-algal cover, to which they readily retreated when disturbed, suggesting they are vulnerable to predators at this small size (Jones, 1984).

Recordings of macro-algal cover used in Chapter Three also showed that natural subtidal areas sampled in Kenepuru Sound had significantly less macro-algal cover than

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similar areas sampled in Pelorus Sound. This is probably due to a lack of suitable substrate or the low light penetration in Kenepuru Sound (Bradford *et al*, 1987). It does, however, suggest that the high mortality of 0+ year-class *N. celidotus* observed in Kenepuru Sound was due to the lower levels of macro-algal cover in this area. It also raises the possibility that high growth rates among adult *N. celidotus* sampled in Kenepuru Sound are due to a lack of macro-algal cover, limiting the number of 0+ year-class individuals making it through their first year in natural subtidal areas.

As an interesting side issue, the timing of spawning is thought to be regulated by water temperature for many fish (Cassie, 1955; Qasim, 1956; Quast, 1968; Warner, 1975). Consequently, populations located in cooler waters at higher latitudes tend to spawn later than populations of the same species in warmer, low-latitude locations (Lagler *et al*, 1962). Orton's Rule summarises this trend by predicting that species nearer to the warmer limits of their range breed during the colder months of the year and, conversely, that species nearer to the colder limits of their range breed during the warmer months of the year (Orton, 1912). This apparent ability of fish populations to vary their time of spawning with changing latitude is thought to ensure that young are able to develop in conditions most favourable to them (Lagler *et al*, 1962). Because young are generally less tolerant to extremes in temperature, they are expected to be brought forth into the environment at a temperature close to the centre of the adults' temperature range (Qasim, 1956).

From observations of courtship displays and increases in aggressive encounters between terminal-phase males, Doak (1972) concluded that for *N. celidotus* generally, spawning occurred from August until September. Using observations of egg abundance off the Otago coast (45°37'S to 45°47'S), Robertson (1973) suggested that *N. celidotus* commenced spawning in August and continued until December. At Leigh (174°45'E to 36°15'S), Jones (1980) sectioned *N. celidotus* gonad tissue and found that all mature females had ripe ovaries from August until December. Graphs of monthly mean gonad weights confirmed this (Jones, 1980). Equivalent graphs of monthly mean gonad weight used in this study indicated that *N. celidotus* in the Marlborough Sounds spawned between October and January (Figure 4.6).

These results show no consistent temporal shift in the time of spawning with changes in latitude as Orton's Rule would predict.

## CHAPTER FIVE

### EXPERIMENTAL REMOVAL OF ENCRUSTING ORGANISMS FROM MOORING ROPES OF MUSSEL FARMS

#### 5.1 INTRODUCTION

Several studies of *Notolabrus celidotus* have been done in the North Island (Choat, 1965; Todd, 1969), most notably by G.P. Jones of Auckland University (Jones, 1980, 1981a, 1981b, 1983, 1984a, 1984b and 1984c). Consequently, much is already known about the diet (Jones, 1984a) and habitat requirements (Jones, 1984b and 1984c) of *N. celidotus*.

The distribution of juvenile *N. celidotus*, like that of many other juvenile reef fish, is closely associated with macro-algae (Jones, 1984a and 1984b). It appears that macro-algae is conducive to the recruitment of *N. celidotus*, providing shelter to small fish that are otherwise vulnerable to predation (Jones, 1984a). A macro-algal removal and addition experiment confirmed this, showing that recruitment of *N. celidotus* generally increased exponentially in relation to macro-algal biomass (Jones, 1984b). Jones (1984b) also showed a depth effect, with recruitment of *N. celidotus* being greater in shallow natural subtidal areas compared to deeper areas with equivalent macro-algal cover.

In my study, the importance of natural subtidal macro-algae was seen in the distribution of newly-recruited (<20mm SL) and juvenile (0+ year-class) *N. celidotus* (Chapters Three and Four). The general pattern emerging is that *N. celidotus* recruit into the shelter of shallow macro-algal habitats, remain closely associated with them throughout the first year of life and then move into deeper, more open habitats as they mature (Jones, 1980, 1984a, 1984b; Chapters Three and Four). However, notable levels of newly-recruited and juvenile *N. celidotus* were also observed among the macro-algae and encrusting invertebrates growing on the mooring ropes of mussel farms in the Kenepuru and Pelorus Sounds (Figure 3.12 and Table 4.1, respectively).



These structures appear to simulate the shallow, macro-algal covered habitat of adjacent natural subtidal areas (Plate 5.1), but on a smaller scale. Consequently, some *N. celidotus* may colonise mussel farms directly by utilising the shelter provided by encrusted mooring ropes rather than migrating into mussel farms from nearby natural subtidal areas (Table 4.1).

In this study, macro-algae and encrusting invertebrates were experimentally manipulated on mooring ropes to determine the effects on recruitment and movement of juvenile *N. celidotus* on mussel farms.

## 5.2 MATERIALS AND METHODS

To investigate the possible roles that the organic encrustations of mooring ropes may play in the recruitment and development of young *N. celidotus*, a removal experiment was done on the mooring ropes of mussel farms in Skiddaw, Kenepuru Sound (Section 1.2.2, Figure 1.1). These farms sat in 10-12 m of water approximately 70 m off shore. The experiment used a simple orthogonal design consisting of four treatments, each replicated on five mooring ropes. The four treatments used are outlined below:

- Control One: To measure natural variations in the abundance levels of *N. celidotus*, five mooring ropes were left untouched (Figure 5.1a).
- Control Two: To simulate the disturbance of installing treatments, five mooring ropes were vigorously brushed by hand (Figure 5.1a). This second control group measured only the effects of imposing treatments on the abundance levels of *N. celidotus*.
- Treatment One: To observe the importance of encrusting organisms in maintaining the abundance levels of *N. celidotus*, five mooring ropes were completely stripped of all encrusting organisms by cutting them off the ropes with a knife edge (Figure 5.1a).
- Treatment Two: To observe the extent to which encrusting organisms are important in maintaining the abundance levels of *N. celidotus*, five mooring ropes were half stripped of all encrusting organisms by cutting them off the ropes with a knife edge (Figure 5.1a). The end quarters of each mooring ropes were stripped leaving the middle half undisturbed (Figure 5.1a).

To counter the possible effects of depth (Jones 1984b) and natural variations between rows of mussel lines, one replicate of each treatment was carried out on the first four mooring ropes of three adjoining mussel farms (Figure 5.1a).

To detect any small-scale movements of fish, divers recorded the size and abundance of *N. celidotus* on both the mooring ropes and in several nearby areas of the mussel farms (Figure 5.1b). First, observations were made at the end 15 m of the associated mussel lines; this was done for both the top and bottom 4 m of the dropper lines (Figure 5.1b). Divers swam down each mooring rope recording fish within a radius of 2.5 m of the rope<sup>1</sup>. Divers then hovered above the concrete mooring blocks and recorded fish in a 5x5x4 m area around it (Figure 5.1b). Three 15x5x4 m transects were also done on the benthos at 10 m intervals from the mooring block; these were perpendicular to the mooring rope above (Figure 5.1b). At the conclusion of fish counts, divers swam back up the mooring ropes measuring the radius of encrusting organisms at three points along its length<sup>2</sup> (Figure 5.1b).

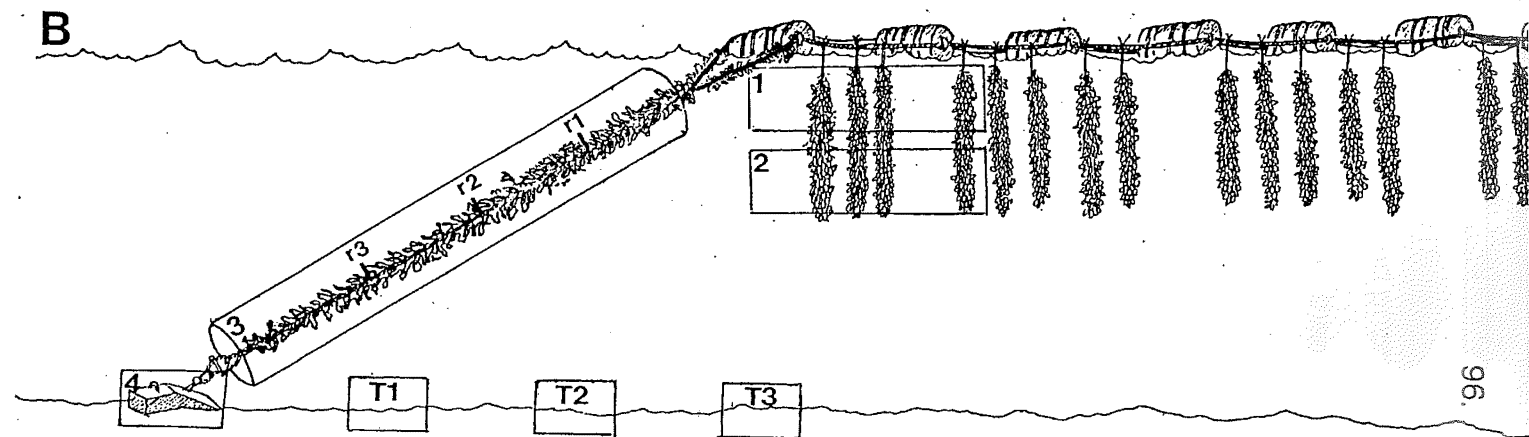
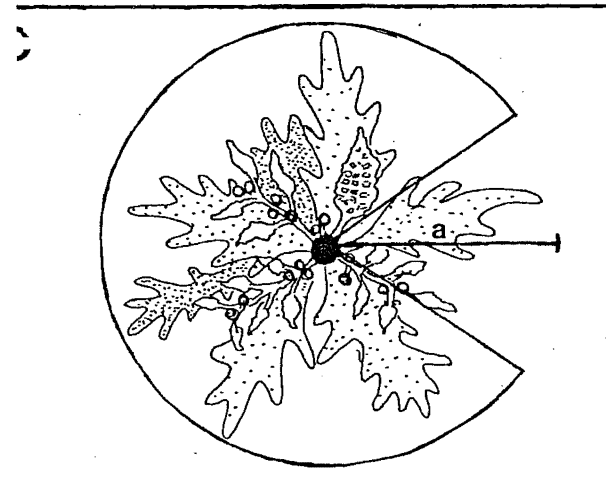
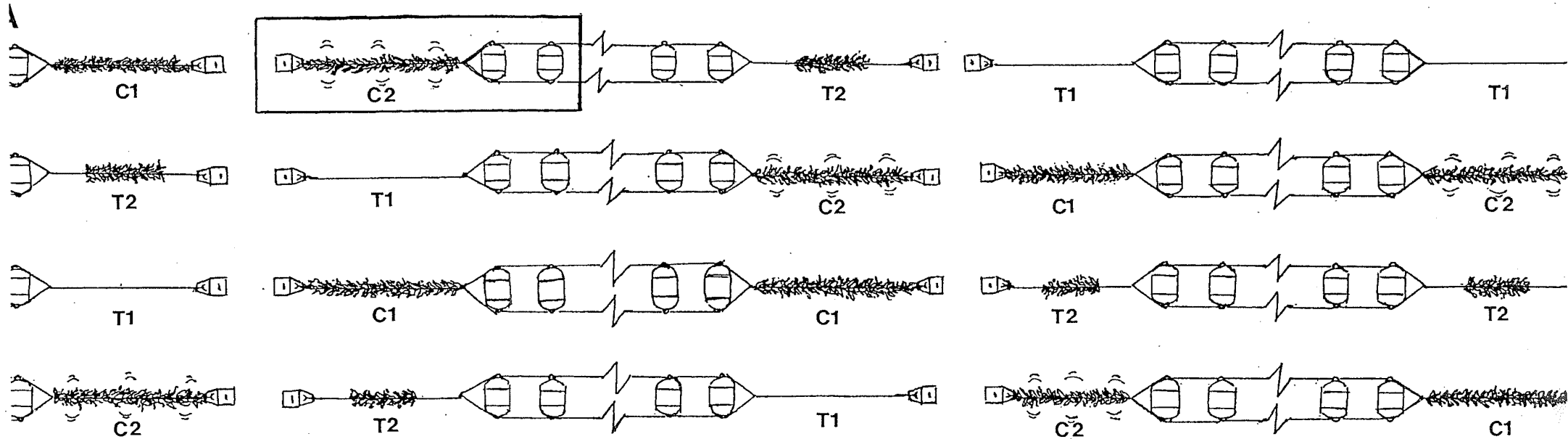
Observations of *N. celidotus* on a mussel farm in Otatara Bay (Pelorus Sound) showed no significant differences in abundances within the daylight hours of three consecutive days ( $F_{(24)}=0.69$ , NS) (Chapter Three). Therefore, observations were made between 0900 and 1600 hours.

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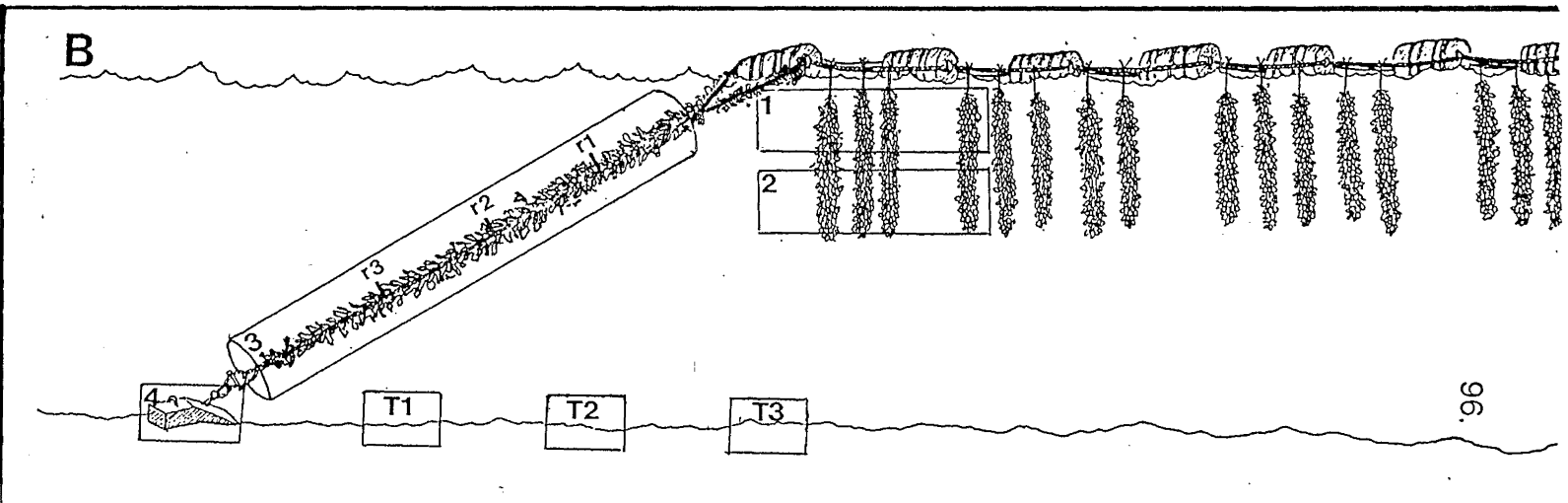
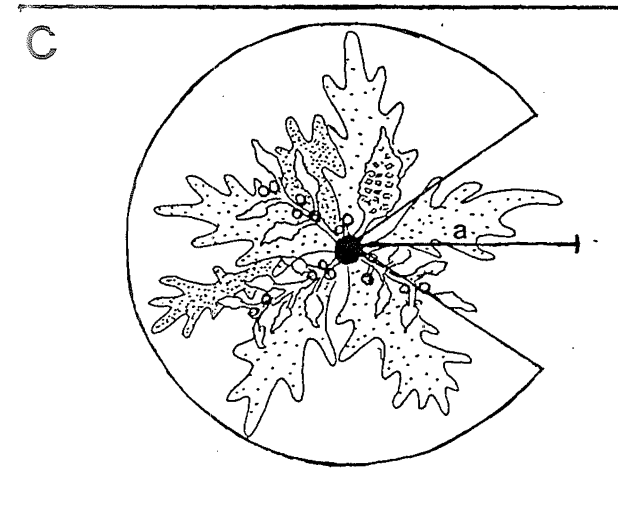
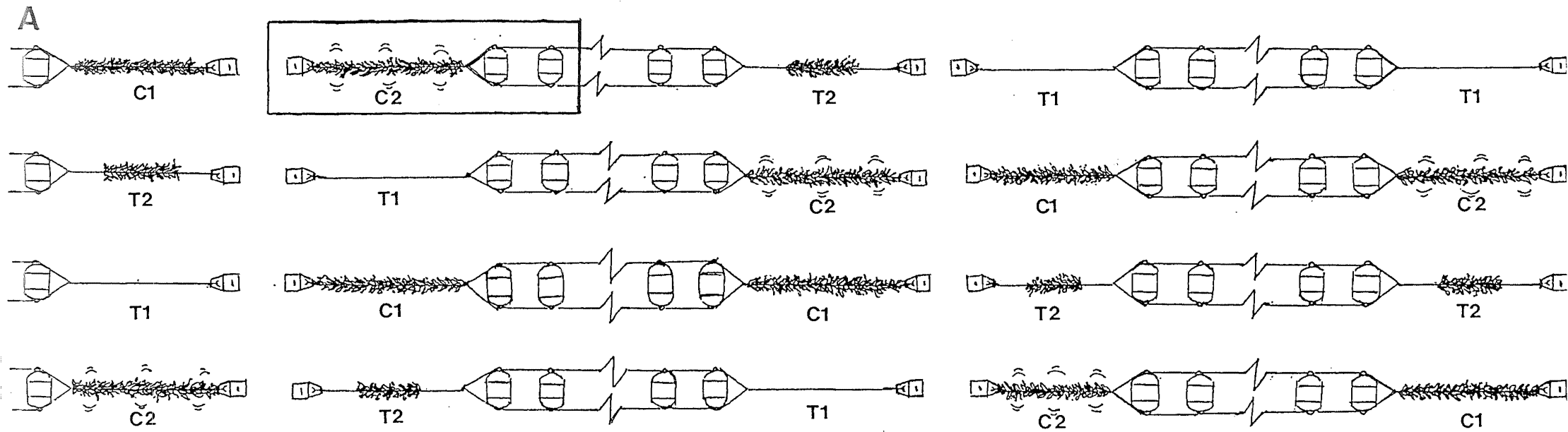
<sup>1</sup> Mooring rope transects were, on average, 32 m long meaning that they sampled approximately 628 m<sup>3</sup>.

<sup>2</sup> On mooring ropes subject to treatment two (ends stripped), the radius of encrustation (Figure 5.1c) was measured in the unstripped area.

Figure 5.1. A) Birds-eye view of the three mussel farms used in the experiment showing the allocation of the four treatments: C1=Control 1, Untouched; C2=Control 2, Brushed, T1=Treatment 1, Stripped; T2=Treatment 2, Ends Stripped. B) Side view of a mooring block and rope at one end of a mussel line. Shown are the locations of transects used to assess fish abundance in each survey. 1=top half of dropper line; 2=bottom half of dropper lines; 3=mooring rope; 4=mooring block; T1-3=15x4 m benthic transects perpendicular to the above mooring rope. The radius of encrustation was measured at three points along the length of each mooring rope, labelled r1-3. C) Cross-section of a mooring rope showing where the radius of encrustation (a) was measured.



C1=Control 1, Untouched; C2=Control 2, Brushed, T1=Treatment 1, Stripped, T2=Treatment 2, Ends Stripped. B) One view of a mooring block and rope at one end of a mussel line. Shown are the locations of transects used to assess fish abundance in each survey. 1=top half of dropper line; 2=bottom half of dropper lines; 3=mooring rope; 4=mooring block; T1-3=15x5x4 m benthic transects perpendicular to the above mooring rope. The radius of encrustation was measured at three points along the length of each mooring rope, labelled r1-3. C) Cross-section of a mooring rope showing where the radius of encrustation (a) was measured.



On 3 June 1992 all areas around experimental mooring ropes were surveyed prior to the implementation of treatments (Figure 5.1a and 5.1b). Treatments were then initiated on 26 June 1992 and observations of *N. celidotus* on mooring ropes were made immediately afterwards. The following day all sample areas were re-surveyed (Figure 5.1b). The experiment was surveyed again in October and December of 1992. However, over spring many of the treatment anchor ropes had a substantial re-growth of macro-algae so treatments were reinstalled on 21 December 1992. The experiment was re-surveyed in late January and March of 1993. *N. celidotus* observed in sample areas were separated into newly-recruited fish (<21mm SL), 0+ year-class (21-86mm SL) and 1+ year-class (87-128mm SL) based on their standard length (read from Figure 4.2c)<sup>3</sup>. The effects of treatments on the densities of juvenile *N. celidotus* were then examined separately for each year-class.

Because transects were not independent with respect to observation times, one-way ANOVAs with Tukey's pairwise comparisons were done between treatments of separate observation periods, provided the heterogeneity of cell variances could be stabilised through a successful transformation. Data transformations and Cochran's tests for homogeneity of variance were used to ensure this. In these tests, a significant result would signify that, at the time of the observation, variations in the abundances of *N. celidotus* between treatment areas were greater than natural variations between rows of mussel farms.

Because three measurements of encrustation were made on each mooring rope, a mean and variance was associated with each replicate rope. Consequently, two-level ANOVAs were used for this variable when comparing the treatments of separate observation periods.

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<sup>3</sup> Although by definition, newly recruited fish are in the 0+ year-class, they are treated as a separate year-class in this section since they serve only as an estimate of recruitment densities.

## 5.3 RESULTS

### 5.3.1 Experimental effects on densities of *Notolabrus celidotus*

Prior to the implementation of treatments, numbers of new recruits (0-20mm SL), 0+ year-class (21-86mm SL) and 1+ year-class (87-128mm SL) *N. celidotus* were relatively evenly spread between treatments (Figures 5.2b, 5.3b and 5.4b). However, mooring ropes were dominated by fish of the 0+ year-class. Consequently, for this area only, the 0+ year-class fish had sufficient numbers to analyze with a one-way ANOVA; there was no treatment effect at this time ( $F_{(3)}=0.58$ , ns).

Directly after treatments were imposed, numbers of smaller *N. celidotus* dropped dramatically on stripped mooring ropes (Figures 5.2b and 5.3b). A one-way ANOVA of the abundance of 0+ year-class *N. celidotus* showed a significant difference between treatments ( $F_{(3)}=4.98$ ,  $p=0.013$ ) and Tukey's pairwise comparisons showed that numbers of fish on stripped mooring ropes (T1) were significantly less than numbers on the untouched ropes (C1). One day later, the effect remained and numbers of *N. celidotus* on stripped mooring ropes were still less than those on untouched ropes (Figures 5.2b, 5.3b and 5.4b). Interestingly, all treatments that disturbed the mooring ropes had noticeable reductions of newly-recruited and 0+ year-class *N. celidotus* a day later; by comparison the untouched mooring ropes remained relatively unaffected (Figures 5.2b and 5.3b). This shows how quickly and easily these animals can respond to even a small habitat disruption.

A day after the installation of treatments, a small increase in the abundance of newly-recruited and 0+ year-class *N. celidotus* was observed on the associated mooring blocks of brushed and half-stripped mooring ropes (Figures 5.2c and 5.3c). Throughout the experiment, the only other area where appreciable numbers of small *N. celidotus* were observed was in the top ends of the associated mussel dropper lines (Figures 5.2a, 5.3a and 5.4a).

At the next observation period in October of 1992 (four months later), some new recruits were seen on the associated mooring blocks of half-stripped mooring ropes (Figure 5.2c) and some 1+ year-class *N. celidotus* were also observed on these

mooring blocks (Figure 5.2c). At this time, a number of 0+ year-class *N. celidotus* were recorded on the associated mooring blocks of untouched mooring lines (Figure 5.3c), but no significant treatment effect was found ( $F_{(3)}=1.01$ , ns). However, most of these fish remained on the mooring ropes, including those that had been stripped some four months earlier (Figure 5.3b). Consequently, in October the abundance of 0+ year-class fish observed on the mooring ropes, like that of the level of encrustation (Section 5.3.2), was not significantly influenced by the treatments used in this experiment ( $F_{(3)}=0.47$ , ns).

In December, six months after treatments were installed, the treatment effect had re-established itself in the levels of encrustation of the mooring ropes (Figure 5.5 and Table 5.1d). However, no significant treatment effect was seen in the abundance of 0+ year-class *N. celidotus* on the mooring ropes ( $F_{(3)}=1.14$ , ns) (Figure 5.3b).

The re-installation of treatments in December resulted in a drop in the densities of 0+ year-class fish on stripped mooring ropes by late January 1993 (Figure 5.3b) ( $F_{(3)}=14.61$ ,  $p<0.001$ ). Tukey's pairwise comparisons showed that the number of these fish on stripped mooring ropes was significantly different to all other experimental groups of mooring ropes.

Interestingly, at this time an increase in both 0+<sup>1</sup> and 1+ year-class *N. celidotus* had occurred in the tops of dropper lines (Figure 5.1b, pos1) associated with untouched (C1) and brushed (C2) mooring ropes (Figures 5.3a and 5.4a). Similar increases in the densities of these two age groups were also noticed on the associated mooring blocks of completely stripped (T1) mooring ropes (Figures 5.3c and 5.4c). At this time, a significant treatment effect was recorded among the densities of 0+ year-class fish observed on mooring blocks of this experiment ( $F_{(3)}=3.93$ ,  $p=0.028$ ). Tukey's pairwise comparisons showed that densities of these fish were significantly higher on the mooring blocks associated with stripped mooring ropes.

Even though the levels of encrustation were similar between treatments in March 1993 (Table 5.1), there was still an observable treatment effect on the abundance of 0+

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<sup>1</sup> 0+ year-class *N. celidotus* observed in 1993 would have recruited in Autumn-Winter 1992.



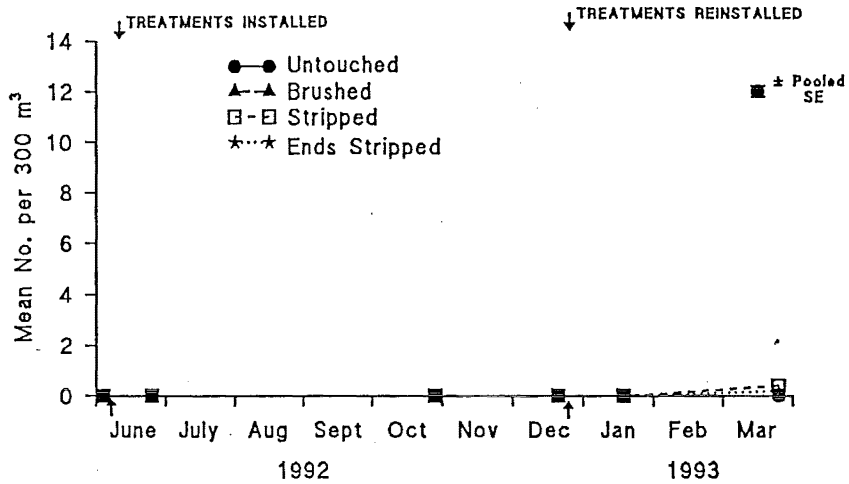
year-class *N. celidotus* on the mooring ropes (Figure 5.3b); however, this was only detectable at the 10% level of significance ( $F_{(3)}=3.12$ ,  $p=0.055$ ).

The number of newly-recruited fish had also decreased on stripped mooring ropes in March of 1992 (Figure 5.2c). Some of these fish may have migrated or recruited onto the tops of dropper lines associated with stripped mooring ropes, as numbers in these areas were slightly higher than in the tops of mussel lines associated with other treatments (Figure 5.2a). However, these were not enough to account for new recruits missing from mooring lines (Figure 5.2a), suggesting that recruitment was reduced in areas associated with stripped mooring lines (Figure 5.2).

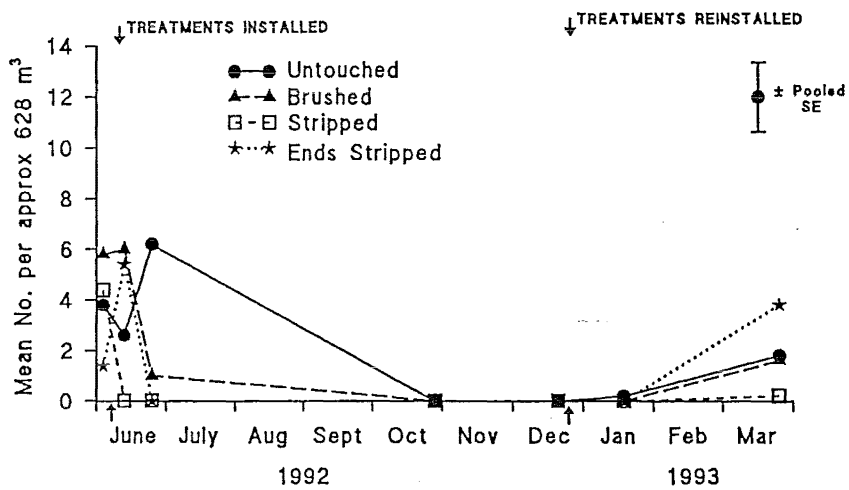
In March of 1992, as in January of 1993, an unusually high number of 0+<sup>1</sup> and 1+ year-class *N. celidotus* were observed on the mooring blocks associated with stripped mooring ropes (Figure 5.3c). This build-up of 0+ year-class fish was a significant treatment effect ( $F_{(3)}=5.98$ ,  $p=0.006$ ). Tukey's pairwise comparisons showed that numbers of these fish on the associated mooring blocks of stripped mooring ropes were significantly higher than on mooring blocks associated with the other three treatments (Figure 5.3c).

Figure 5.2: Mean numbers of newly-recruited *Notolabrus celidotus* (<20mm SL) counted at successive observation periods. Only three survey areas had fish: A) The tops of dropper lines; B) Mooring Ropes; C) Mooring Blocks. A description of these areas is given in Figure 5.1b. Treatments were applied only to mooring ropes; other areas are associated with treatment mooring ropes. The pooled standard error is plotted.

**A** Tops of dropper lines



**B** Mooring Ropes



**C** Mooring Blocks

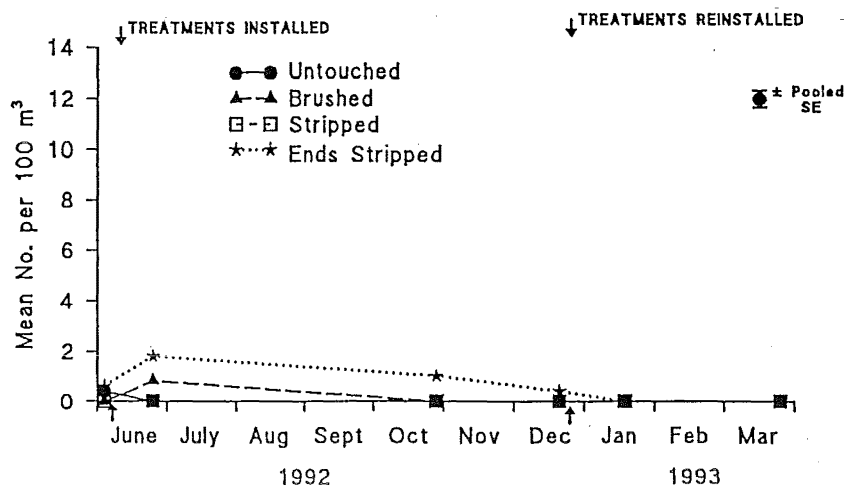
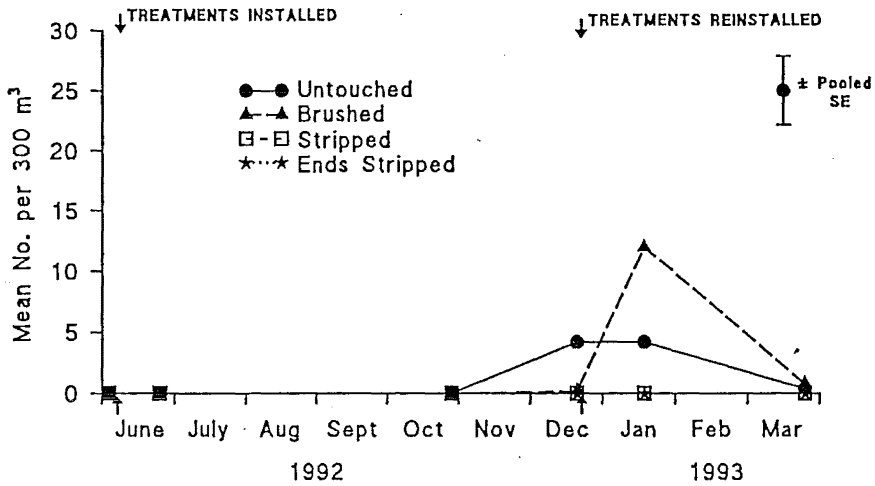
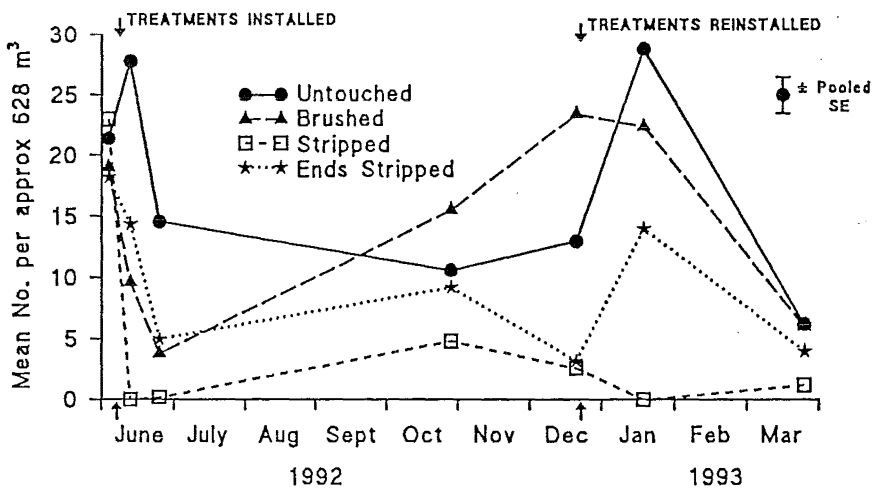


Figure 5.3: Mean numbers of 0+ year-class (21-86mm SL) *Notolabrus celidotus* counted at successive observation periods. Only three survey areas had fish: A) The tops of dropper lines; B) Mooring Ropes; C) Mooring Blocks. A description of these areas is given in Figure 5.1b. Treatments were applied only to mooring ropes; other areas are associated with treatment mooring ropes. The pooled standard error is plotted.

**A** Tops of dropper lines



**B** Mooring Ropes



**C** Mooring Blocks

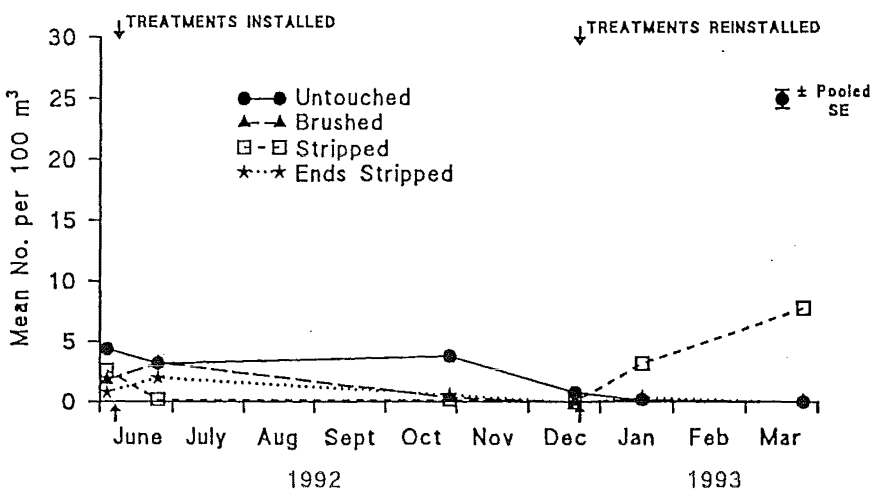
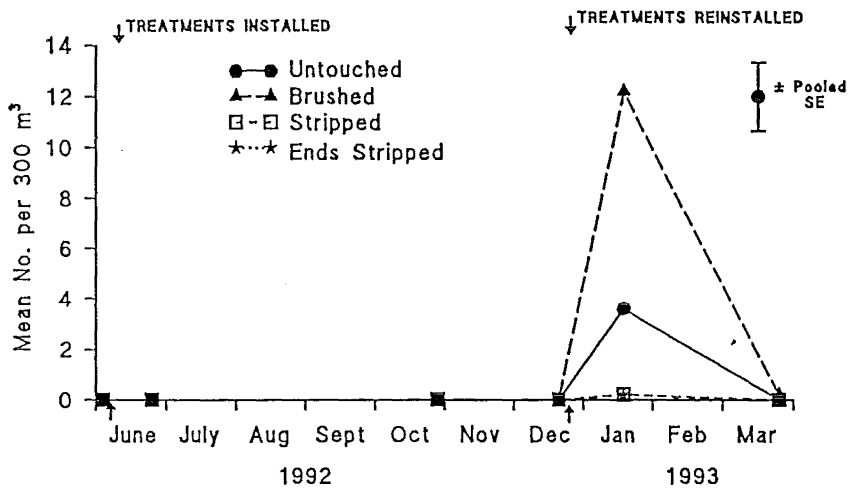
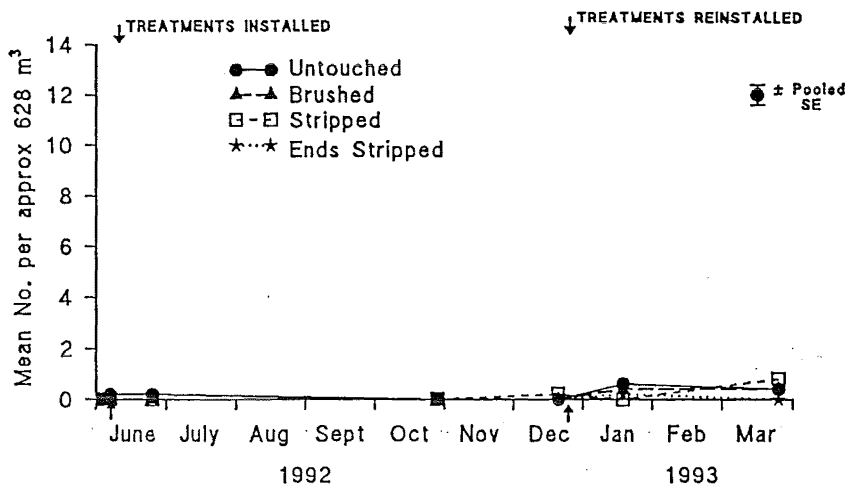


Figure 5.4: Mean numbers of 1+ year-class (87-128mm SL) *Notolabrus celidotus* counted at successive observation periods. Only three survey areas had fish: A) The tops of dropper lines; B) Mooring Ropes; C) Mooring Blocks. A description of these areas is given in Figure 5.1b. Treatments were applied only to mooring ropes; other areas are associated with treatment mooring ropes. The pooled standard error is plotted.

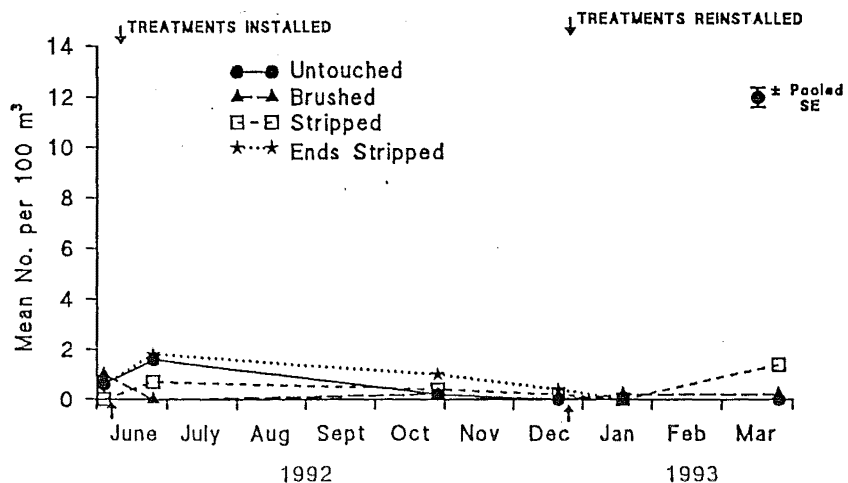
**A** Tops of dropper lines



**B** Mooring Ropes



**C** Mooring Blocks

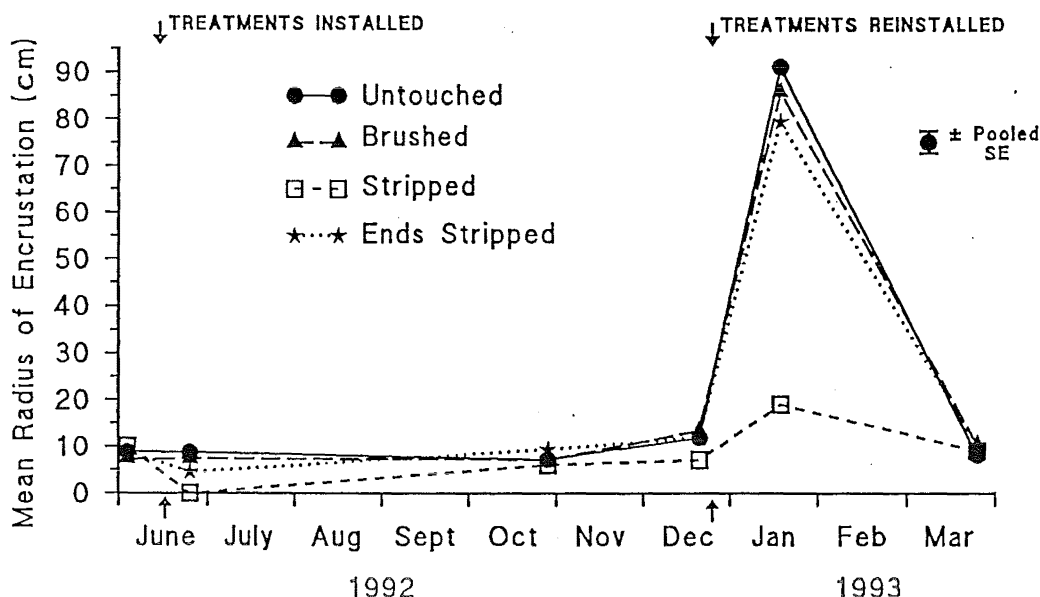


### 5.3.2 Experimental effects on levels of encrustation

Prior to the implementation of treatments, levels of encrustation were similar on mooring ropes of all treatments (Table 5.1a and Figure 5.5). Most (53%) of the variation observed at this time was attributed to differences between individual ropes within treatments (Table 5.1a). However, after treatments were implemented they accounted for 61.5% of the variations observed among levels of encrustation on mooring ropes in the experiment (Table 5.1b and Figure 5.5).

By late October (4 months later) there was significant re-growth of encrusting organisms on mooring ropes and differences between treatments were no longer significant (Table 5.1c and Figure 5.5). However, this result should be treated with some caution, as the method used to evaluate levels of encrustation measured length only. Established encrustations on mooring ropes were relatively dense and consisted of several macro-algae and invertebrate species, whereas over this period the much thinner re-growth was primarily made up of an unidentified, seasonal red macro-algae. Yet with the onset of summer and increasing growth of many resident species such as the macro-algae *Codium fragile*, the treatment effect was re-established by the December observation period (Table 5.1d and Figure 5.5).

Figure 5.5: Mean measurements of encrustation made on mooring ropes of each treatment throughout the duration of the experiment. The radius of the organisms encrusting each mooring rope was measured at three points along its length. The pooled standard error is shown.



Following the observation period in December, treatments were re-installed to test for a treatment effect during the summer months (Figure 5.5). By late January of 1993, considerable growth of the established encrustations had occurred (Figure 5.5). This meant a highly significant treatment effect was observed in the January observation period (Table 5.1e). At this time, almost 85% of the variation among encrustations of mooring ropes was attributed to the treatment effect.

By the last survey in March of 1993, the levels of encrustation had dropped dramatically (Figure 5.5). The encrusting organisms decreased in size at the onset of autumn (Figure 5.5) and, at this stage, there was no longer a difference among treatments of the experiment.

**Table 5.1:** ANOVAs of measurements of mooring rope encrustation made during each observations period. The radius of the organisms encrusting each mooring rope was measured at three points along its length. A description of treatments and their allocations are shown in Figure 5.1. A Cochran's test was used to test homogeneity of variances. The percentages of the total variance accounted for by each factor are given; formula from Winer (1971).

Source	df	MS	F	P	%
<b>A. Pre-treatment radius of encrusting organisms on mooring ropes<sup>1</sup></b> 3-June 1992.					
Treatment	3	19.044	2.04	ns	8.1
Rope(Treatments)	16	22.017	2.36	0.014	53.0
Residual	40	9.333			38.9
Total	59				
<b>Treatments installed 26-June 1992</b>					
<b>B. One day post-treatment radius of encrusting organisms on mooring ropes<sup>2</sup></b> 27-June 1992.					
Treatment	3	224.022	38.08	<0.001	61.5
Rope(Treatments)	16	15.558	2.64	0.006	13.6
Residual	40	5.883			24.9
Total	59				
<b>C. Three months post-treatment radius of encrusting organisms on mooring ropes<sup>3</sup></b> 28-October 1992.					
Treatment	3	28.110	2.31	ns	5.4
Rope(Treatments)	16	31.320	2.57	0.008	32.5
Residual	40	12.180			62.1
Total	59				
<b>D. Six months post-treatment radius of encrusting organisms on mooring ropes<sup>4</sup></b> 20-December 1992.					
Treatment	3	115.400	5.57	0.003	22.4
Rope(Treatments)	16	24.200	1.17	ns	4.1
Residual	40	20.700			62.1
Total	59				
<b>Treatments Reinstalled 21- December 1992</b>					
<b>E. 38 days post-2<sup>nd</sup> treatment radius of encrusting organisms on mooring ropes<sup>5</sup></b> 18-January 1993.					
Treatment	3	16341.50	89.95	<0.001	84.9
Rope(Treatments)	16	211.20	1.16	ns	0.0
Residual	40	181.70			14.3
Total	59				
<b>F. 3 months post-2<sup>nd</sup>-treatment radius of encrusting organisms on mooring ropes<sup>6</sup></b> 24-March 1993.					
Treatment	3	17.528	2.53	ns	2.7
Rope(Treatments)	16	63.817	9.20	<0.001	71.3
Residual	40	6.933			26.1
Total	59				

1. Cochran's test  $C=0.1357$ , not significant (20 variances, 3 df)
2. Cochran's test  $C=0.2153$ , not significant (20 variances, 3 df)
3. Cochran's test  $C=0.1040$ , not significant (20 variances, 3 df)
4. Cochran's test  $C=0.1570$ , not significant (20 variances, 3 df)
5. Cochran's test  $C=0.1536$ , not significant (20 variances, 3 df)
6. Cochran's test  $C=0.1177$ , not significant (20 variances, 3 df)

### 5.3.3 Relationships between levels of encrustation and densities of *Notolabrus celidotus*

New recruits (<20mm) were conspicuously absent on mooring ropes from which encrusting assemblages were removed (Figure 5.6c). On the brushed and half-stripped mooring ropes, new recruits (1992) appear to have undergone a short-term dispersal following the first treatment installation (Figures 5.6b and 5.6d). However, in the following year new recruits seem to have been unaffected by these two treatments (Figures 5.6b and 5.6d). The greatest numbers of new recruits were seen on the undisturbed mooring ropes in June of 1992 (Figure 5.6a); although the presence of new recruits is only a delayed estimate of actual recruitment, the true levels of recruitment onto these mooring ropes probably peaked sooner than Figure 5.6a would imply. Nonetheless, these results support observations made in Chapter Three that recruitment of *N. celidotus* in the Kenepuru and Pelorus Sounds begins in summer and peaks in autumn.

Observations of levels of encrustation on the mooring ropes showed a period of rapid growth during summer; the early recruitment of *N. celidotus* appears to coincide with this event (Figures 5.6a, 5.6b and 5.6c). Unlike new recruits, 0+ year-class *N. celidotus* were present on mooring ropes throughout the year (Figures, 5.7a, 5.7b, 5.7c and 5.7d). Their relationship with the level of shelter provided by the encrustations of mooring ropes is much more obvious. On undisturbed mooring ropes, numbers of 0+ year-class *N. celidotus* appear to be directly influenced by the amount of shelter provided (Figure 5.7a). This relationship, although not as clear, was also seen on brushed mooring ropes (Figure 5.7b). On ropes from which a quarter of the encrustation was stripped from each end (note the radius of encrustation was measured in the untouched half), only around half the number of 0+ year-class fish were present compared to the control mooring ropes over summer (Figure 5.7d). This suggests a direct relationship between 0+ year-class *N. celidotus* and levels of mooring rope encrustation. However, the relationship between levels of shelter provided by the encrustations and densities of 0+ year-class *N. celidotus* is most clearly seen when the encrustations are removed and fish subsequently depart (Figure 5.7c).

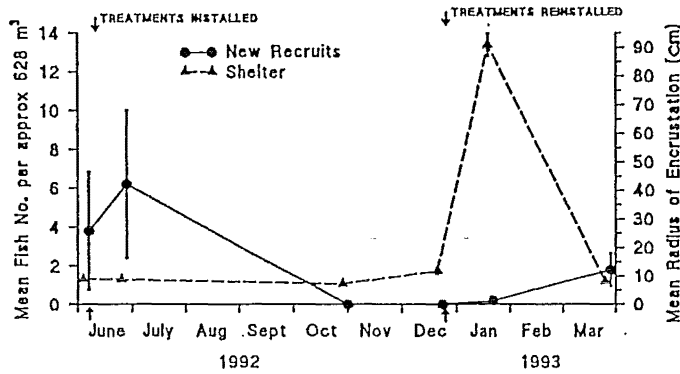


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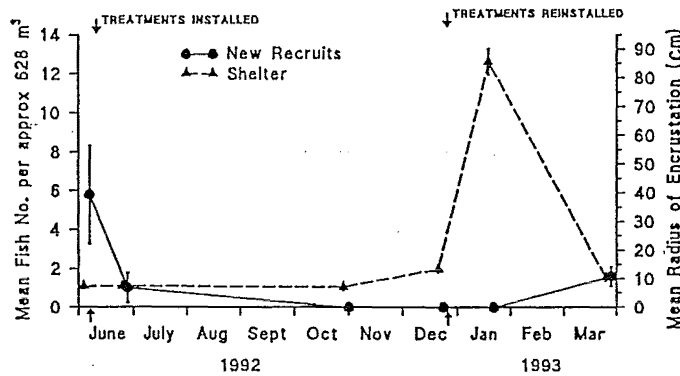
*N. celidotus* of the 1+ year-class were relatively scarce on the mooring ropes used in this experiment (Figures 5.8a, 5.8b, 5.8c and 5.8d). Although fish numbers increased marginally with the rapid growth in levels of encrustation over summer (Figures 5.8a and 5.8b), they do not appear to be as dependent on this as are the new recruits and the 0+ year-class. Yet, both the partial and complete stripping of encrustations from mooring ropes appeared to reduce the number of 1+ year-class *N. celidotus* in these areas (Figures 5.8c and 5.8d).

Figure 5.6: Mean ( $\pm$  se) numbers of newly-recruited (<20mm SL) *Notolabrus celidodus* and mean ( $\pm$  se) radius of encrustation (shelter) recorded on the mooring ropes (n=5) of each treatment (n=4) at successive observation periods. Treatments applied to mooring ropes were: A) Untouched; B) Brushed; C) Completely stripped; D) Stripped at each end quarter.

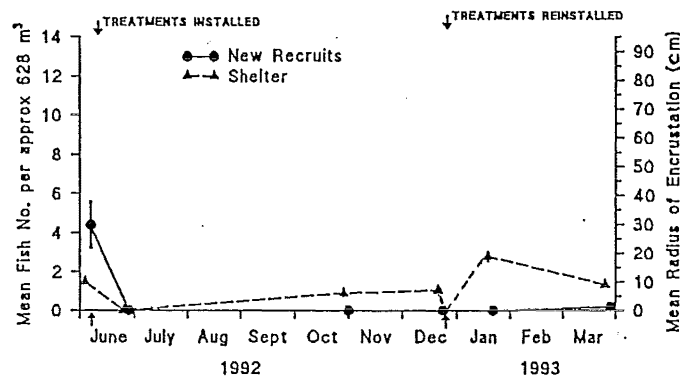
**A Untouched Mooring Ropes**



**B Brushed Mooring Ropes**



**C Stripped Mooring Ropes**



**D Half Stripped Mooring Ropes**

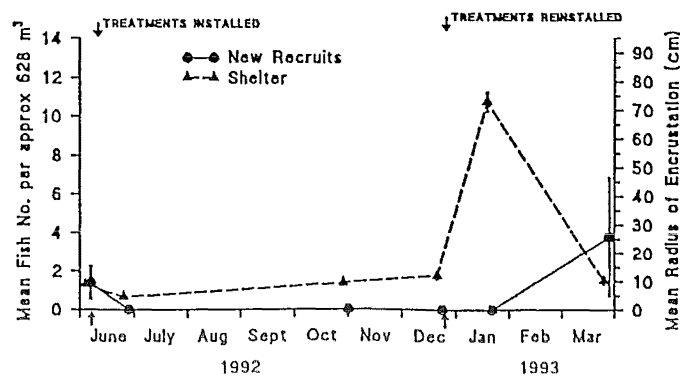
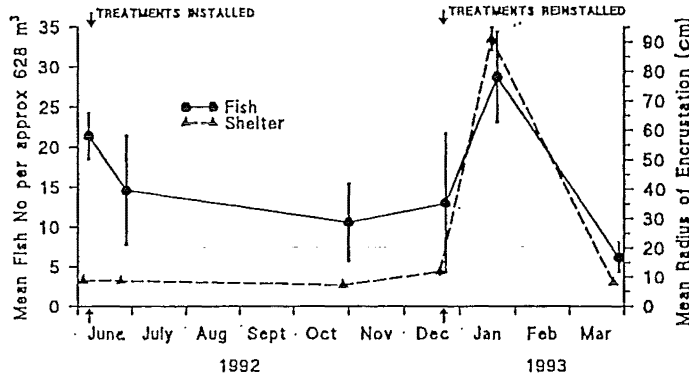
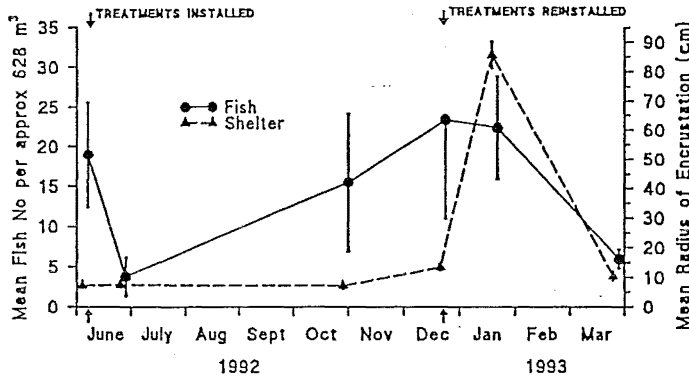


Figure 5.7 Mean ( $\pm$  se) numbers of 0+ year-class (21-87mm SL) *Notolabrus celidotus* and mean ( $\pm$  se) radius of encrustation (shelter) recorded on the mooring ropes (n=5) of each treatment (n=4) at successive observation periods. Treatments applied to mooring ropes were: A) Untouched, B) Brushed; C) Completely stripped; D) Stripped at each end quarter.

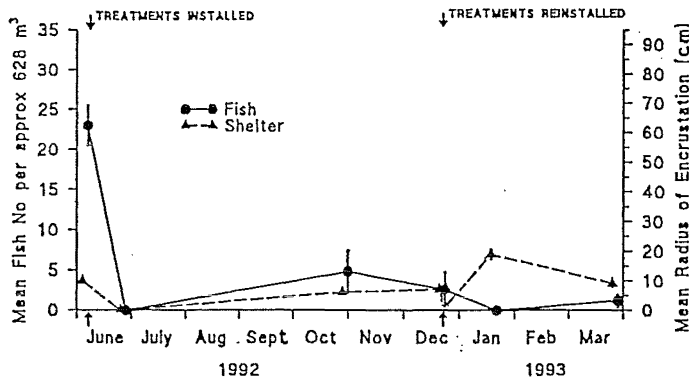
**A Untouched Mooring Ropes**



**B Brushed Mooring Ropes**



**C Stripped Mooring Ropes**



**D Half Stripped Mooring Ropes**

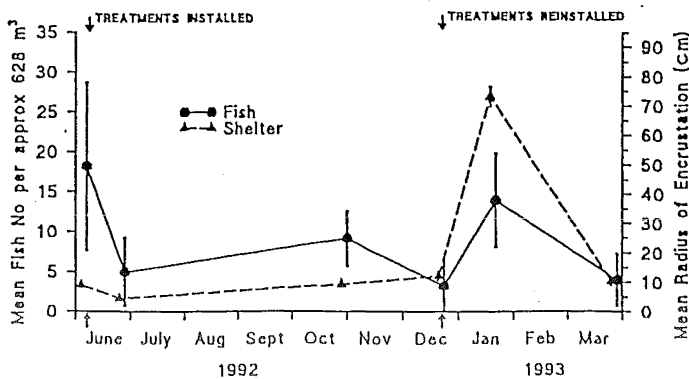
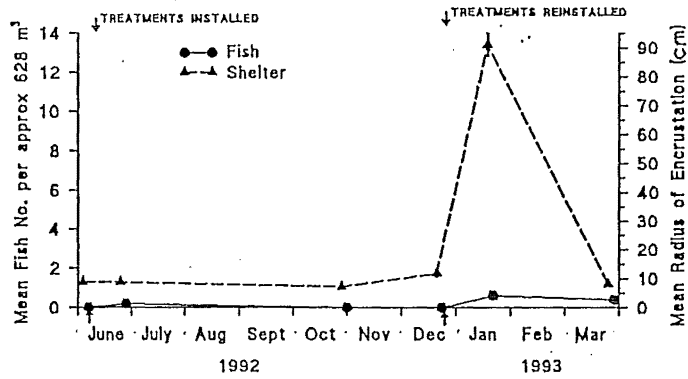
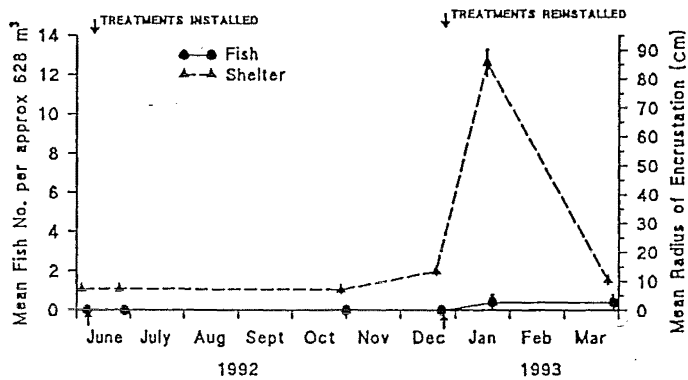


Figure 5.8 Mean ( $\pm$  se) numbers of 1+ year-class (87-128mm SL) *Notolabrus celidotus* and mean ( $\pm$  se) radius of encrustation (shelter) recorded on the mooring ropes (n=5) of each treatment (n=4) at successive observation periods. Treatments applied to mooring ropes were: A) Untouched; B) Brushed; C) Completely stripped; D) Stripped at each end quarter.

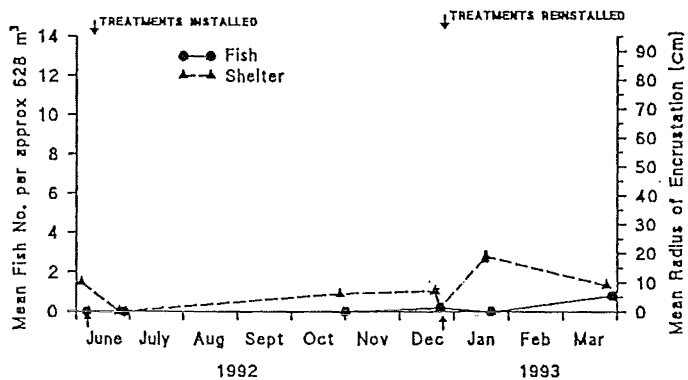
**A Untouched Mooring Ropes**



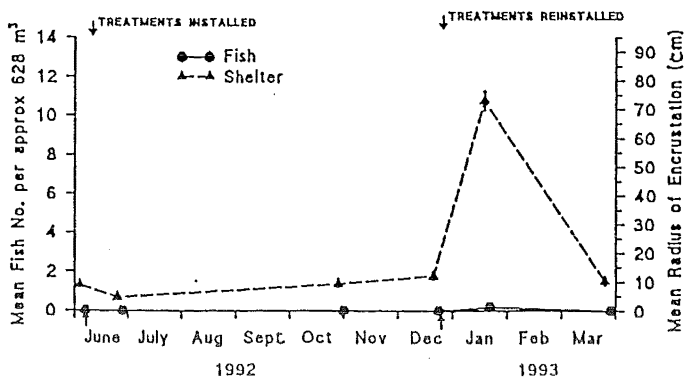
**B Brushed Mooring Ropes**



**C Stripped Mooring Ropes**



**D Half Stripped Mooring Ropes**



#### 5.4 Discussion

The importance of shelter in facilitating the recruitment and development of juvenile reef fish is well known. Several studies have observed reef fish populations using shallow macro-algae as a habitat for recruitment and development of juveniles (references listed in Jones 1984b and 1988). In the marine reserve at Leigh, Jones (1984b) observed this characteristic among populations of *Notolabrus celidotus* recruiting mainly into shallow furoid macro-algae. From his experiments, Jones (1984b) concluded that the relationship between densities of juvenile *N. celidotus* densities and macro-algal weight was exponential.

The importance of shallow macro-algae for small *N. celidotus* has been primarily attributed to the shelter it affords its inhabitants (Jones 1984a). However, the many potential epifaunal food items provided by macro-algae may also account for its suitability as a point of recruitment (Jones, 1984b), since newly-recruited *N. celidotus* (<20 mm FL) consume mainly benthic copepods (Taylor, 1991). However, this requirement quickly dissipates, since planktonic copepods and cladocerans comprise 90% of the diet of *N. celidotus* >20mm fork length (Taylor, 1991).

The shelter provided by the encrustations growing on the mooring ropes of mussel farms in the Marlborough Sounds also appears to facilitate the recruitment and development of juvenile *N. celidotus*. In the experiment discussed here, stripping mooring ropes of encrusting assemblages had a dramatic effect on the local abundance of both newly-recruited and 0+ year-class *N. celidotus*. The immediate effect of stripping mooring ropes was to remove all fish from these sites (Figures 5.3b, 5.4b and 5.5b). However, even a small disruption of the encrustations reduced numbers of *N. celidotus* on mooring ropes a day after treatments were imposed (Figures 5.3b, 5.4b and 5.5b). This shows the sensitive nature of these fish to environmental disruptions. A more obvious relationship between the levels of encrustation and the abundance of juvenile *N. celidotus* was seen over summer when a natural increase in the size of mooring rope encrustations gave more weight to treatment effects (Figures 5.7a, 5.7b, 5.7c, and 5.7d). A clear cause and effect relationship was seen between the removal of encrustations in December and the abundance of 0+ year-class *N. celidotus* observed

on mooring ropes in January of 1993 (Figure 5.4b). For these fish, the relationship between the level of encrustation and abundance appears to be linear, since the total removal of encrustations from mooring ropes led to a complete absence of fish and half removal led to half the number of fish observed on control mooring ropes (Figure 5.4b). It also appears that, once established, this relationship persists (Figure 5.4b) even after the treatment effect is no longer observable in levels of encrustation on the mooring ropes (March, Figure 5.2).

Recruitment of *N. celidotus* onto the mooring ropes of mussel farms also appears to be directly influenced by the level of encrustation on these ropes (Figure 5.3b). New recruits observed in March of 1993 were dramatically reduced in number on stripped mooring ropes, even though treatment effects were no longer observable in levels of encrustation (March, Figure 5.2). However, it is most likely that when these new recruits arrived some time in late summer, a treatment effect was present (Figure 5.2). Consequently, it appears that patterns of recruitment were set by the level of encrustation at settlement and that these patterns persisted until these fish were large enough to be observed (Figure 5.4).

Over summer, a large increase in numbers of juvenile *N. celidotus* on the anchor ropes (Figure 4.b) and along the tops of mussel dropper lines associated with control mooring ropes was observed (Figure 5.4a and 5.5a). The presence of these fish cannot be explained by comparative numbers of recruits observed in other areas of the mussel farms. These observations support the conclusions made in Chapters Three and Four that these fish are migrants from nearby natural subtidal areas where very high levels of recruitment were observed (Figure 3.12 and Table 4.1).

An accumulation of 0+ and 1+ year-class *N. celidotus* was also observed on the mooring blocks associated with stripped mooring ropes (Figure 5.4c). It appears that these fish were inshore migrants whose access to mussel dropper lines was stopped by the complete stripping of these mooring ropes. This result suggests that encrusted mooring ropes may also act as a gateway through which fish migrating from natural subtidal areas gain access to the dropper lines of mussel farms.

If *N. celidotus* are predominately recruiting and developing in the naturally

occurring macro-algae of natural subtidal areas and migrating to adjacent mussel farms, when stripping mooring ropes will not be effective in reducing their numbers on mussel arms. However, this does not apply to new recruits which appear to be removed from arms by stripping mooring ropes (Figure 5.2).

On the basis of these results, I conclude that the amount of organic encrustation growing on mooring ropes can directly affect the number of *N. celidotus* recruiting into mussel farms. However, the stripping of mooring ropes is not likely to be an effective means of controlling numbers of 0+ and 1+ year-class *N. celidotus* because of their apparent ability to migrate from nearby natural subtidal areas, where substantial recruitment occurs.

From my study, it is not possible to determine the relative importance of attributes such as food and shelter provided by the encrusting organisms of mooring ropes. To address this question, methods to independently manipulate these attributes will need to be developed.

## CHAPTER SIX

### GENERAL DISCUSSION

The study sought to investigate some of the potential factors influencing the ecology (especially in relation to recruitment) of *Notolabrus celidotus* resident on and around mussel farms in Kenepuru and Pelorus Sounds. This involved an examination of factors operating at several stages in the life history of these fish<sup>1</sup>. Although reef phase and planktonic observations made in this survey were static (i.e., confined to within one generation) they can be used as estimates of the abundance and distribution of single year-classes moving through the life history stages of *N. celidotus*, provided that a stationary age distribution is assumed. Jones' (1981a, 1984b, 1984c) finding of consistent recruitment in North Island *N. celidotus* populations between years for different habitats lends support to this assumption. All stages of the complex life history of this labrid appear to have played an important role in shaping the size and structure of *N. celidotus* populations observed in this study. This final chapter briefly reviews the main findings of this study with regard to current theories of reef fish population regulation and to the potential amelioration of predation by *N. celidotus* on mussel farms.

A spatially-stratified survey of surface plankton in Kenepuru Sound, Hikapu Reach and Pelorus Sound showed that teleost eggs were, by far, most abundant in Kenepuru Sound. It appears that a seaward moving, low-salinity layer of surface water (Heath, 1974a, 1976, 1982; Carter, 1976; Bradford *et al*, 1987) determines the distribution of fish eggs by flushing them from Hikapu Reach and concentrating them at its ebb in Kenepuru Sound. Predation by the planktivorous jellyfish, *Aurelia aurita*, was also implicated as a factor affecting the spatial distribution of teleost eggs in the Beatrix-Clova-Crail Bay complex of Pelorus Sound. In this area teleost egg numbers were unusually low and *A. aurita* reached prolific densities. Consequently, even by the egg phase of planktonic development, less than 120 hours post fertilization (Robertson, 1973), the abundance patterns of *N. celidotus* offspring appeared to be determined more by features of the

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<sup>1</sup> For more detailed observations of adult phases of *N. celidotus* observed in this survey see Clarke (1993).



pelagic environment than by the distribution of sexually mature adults. Furthermore, it was clear from visual transects done at sites within Kenepuru and Pelorus Sounds that the spatial distribution and abundance of *N. celidotus* recruits reflected the abundance patterns of planktonic eggs more than the distribution of sexually mature adults. The implication here is that pre-recruitment processes operating in the pelagic environment continued to influence the densities of settling and subsequently recruiting *N. celidotus*. This is consistent with many other studies which have concluded that properties of the pelagic environment acting on the distribution of ichthyoplankton can continue to be observed in the distribution of newly-recruited juvenile reef fish (Barlow, 1981; Stephens and Zerba, 1981; Victor, 1983, 1986; Connell, 1985; Doherty, Williams and Sale, 1985; Kingsford and Choat, 1986; Kingsford, 1988 & 1990; Kingsford *et al*, 1991). Many ecologists have further suggested that spatial and temporal changes in the distribution of reef fish are primarily a consequence of patterns laid down during the settlement and subsequent recruitment of juveniles from the plankton (Barlow, 1981; Stephens and Zerba, 1981; Victor, 1983, 1986; Cowen, 1985; Doherty, Williams and Sale, 1985; Kingsford and Choat, 1986; Kingsford, 1988; Kingsford, Wolanski and Choat, 1991).

Visual strip transects were used in this study to estimate the abundance levels and structure of reef phase *N. celidotus* both on mussel farms and adjacent natural subtidal areas in sites of Kenepuru and Pelorus Sounds. The spatial factors which accounted for most of the observed variation of these fish were at a very localised scale. Marked differences were found in the recruitment, juvenile and adult densities of *N. celidotus* within specific areas of mussel farms and between farms and their adjacent natural areas of coastline. These patterns were generally consistent over a large spatial scale.

Newly recruited and juvenile *N. celidotus* were most abundant in algal covered patches inshore of mussel farms where they aggregated in loose groupings associated with patches of macro-algae. The dominant algal species in these areas was *Cystophora scalaris*; this was very patchy in its distribution and significantly more abundant in Pelorus Sound. As with many other juvenile reef fish, densities of juvenile *N. celidotus* were significantly correlated with macro-algae in these shallow areas, leading to a patchy

distribution of these fish. Adults, on the other hand, were most abundant in deeper, more open water around the mooring blocks of mussel farms (also see Clarke 1993). Although some recruits and juvenile fish were observed in the encrustations growing on mooring ropes, few fish, other than the blennoid *Forsterygion varium*, were consistently seen on the vertically suspended dropper lines of mussel farms. However, a small increase in numbers of large juvenile *N. celidotus* was observed in these areas over the summers of both 1991 and 1992. The general pattern emerging is that *N. celidotus* recruit into the shelter of shallow macro-algal habitats, remain closely associated with them throughout a period of development and diet change (Jones, 1984a, 1984b) and then move into deeper, more open habitats as they mature (Jones, 1984a, 1984c). Since only low levels of recruitment were observed on mussel farms, it is likely that most adult and large juvenile *N. celidotus* resident on farms migrated there from adjacent natural subtidal areas where recruitment was relatively high and adults relatively rare. The appearance of these large juveniles on the dropper lines of mussel farms each summer further suggests that the migration into mussel farms occurs via this area and at this time.

The spatial distributions of *N. celidotus* populations observed in this survey were consistent with populations previously observed in more natural environments in the North Island (Jones, 1980, 1981a, 1983, 1984a, 1984b and 1984c). Observations of *N. celidotus* within days on a mussel farm showed reasonably high levels of stability in spatial abundance patterns at this temporal scale. As found in studies of other reef fish in New Zealand, it seems that for *N. celidotus* observed in this study, seasonal and yearly variations can emphasize patterns of spatial variation, but they do not over-ride them.

Apart from the 0+ year-class, *N. celidotus* densities both on mussel farms and in adjacent natural subtidal areas in Kenepuru Sound were comparable to populations observed by Jones in natural coastal areas at both Wellington and Leigh (Jones, 1980). However, compared to these areas, the total densities of *N. celidotus* observed in sites in Pelorus Sound were six times as high in natural subtidal areas and twenty times as dense as fish observed in transects done at an equivalent depth to those done under

mussel farms. Densities of 0+ year-class *N. celidotus* in Pelorus Sound were almost twice as high as those in Kenepuru Sound and more than eight times that observed by Jones in the North Island (Jones, 1980).

Basic in any biological population is that numbers are held at some fluctuating level by natural controls. Overall numbers of *N. celidotus* in this study were remarkably higher than populations observed by Jones (1980, 1981a). It has been suggested that the numbers and spatial distribution of reef fish are predominantly determined by temporal and spatial variations in the number of settlers arriving and subsequently recruiting into an area from the plankton (Jones, 1981a, 1984c; Doherty, 1983). Observations made in this study showed that large numbers of planktonic *N. celidotus* eggs and new recruits accumulated in Kenepuru Sound, apparently as the result of hydrological processes operating in the pelagic environment. By comparison, densities of both egg-phase and newly recruited *N. celidotus* were less in sites in Pelorus Sound. Unfortunately no such estimates of planktonic egg numbers are available for areas studied by Jones (1980, 1981a). Plankton surveys done by Robertson (1973) off the Otago coast show considerable temporal variations in the densities of *N. celidotus* egg numbers and, therefore, cannot be directly compared with the one-off survey in this study. In Robertson's (1973) study, densities of *N. celidotus* eggs were similar to those observed in this study at the same time of year; no density estimates of 'reef' phase *N. celidotus* were made in that area. Therefore, it is not possible to estimate if higher densities of 'reef' phase *N. celidotus* are characterised by high densities of planktonic eggs beyond sites observed in this survey. However, estimates of recruitment were made by Jones (1981a, 1984b, 1984c) for several North Island *N. celidotus* populations. Although his methods of estimating recruitment differed from those used in this study, it appears that recruitment in Kenepuru and Pelorus Sounds was considerably higher. However, the most accurate and direct comparison of early life history phases of *N. celidotus* between this and other studies is the 0+ year-class. There were substantially more 0+ year-class *N. celidotus* observed in sites in Kenepuru and Pelorus Sounds than observed by Jones in more natural areas in the North Island. It therefore appears that populations observed in Kenepuru and Pelorus Sounds were able to grow larger simply

because they have the potential to do so. However, it is still unclear how populations of *N. celidotus* observed in this study can acquire such large cohorts of young fish compared to other areas. It would seem that the high densities observed in this study were manifested at a very early stage in the life history of these animals. Perhaps the low tidal exchange in the Kenepuru and Pelorus Sounds allows a build up of planktonic stock that would otherwise be swept away in coastal areas. A more detailed investigation of spatial and temporal patterns of abundance in plankton and 'reef' phases of *N. celidotus* in Kenepuru and Pelorus Sounds done simultaneously with an equivalent investigation of coastal populations would be required to confirm this.

Recruitment is a relatively brief event marking the beginning of the major part of the life cycle of most reef fish. Consequently, throughout this long 'reef' phase, post-recruitment processes such as competition, predation and other such factors could exert sufficient influence to over-ride the effects of settlement and recruitment patterns (Stephens *et al*, 1970; Sale, 1976). In this study, this appears to have occurred in Kenepuru Sound since the effect of hydrological processes are not reflected in the densities of juvenile and adult *N. celidotus* when compared to the larger numbers observed in Pelorus Sound, where eggs and new recruits were less dense. Among coastal populations of *N. celidotus* in the North Island, Jones (1981a) found that densities of adult *N. celidotus* did reflect levels of recruitment (1984c). From this he concluded that a build-up of adult *N. celidotus* in an area was due to consistently high recruitment in that area over a period of years (Jones, 1984b). However, this relationship was not as simple in areas surveyed in this study where densities of adult and especially juvenile *N. celidotus* were much higher and did not simply reflect those of juvenile recruitment. Obviously a build up of *N. celidotus* numbers has occurred in Pelorus Sound, probably due to consistent recruitment followed by an increase in adult habitat provided by mussel farms. However, using the same logic, densities of *N. celidotus* observed in Kenepuru Sound should be twice as high as those in Pelorus Sound since twice the level of recruitment was observed in that area. Clearly this is not the case.

To what degree patterns of reef fish distribution and abundance are determined by pre-recruitment and post-recruitment processes has been a topic of some debate. However, recent work on coral reef fish has shown that adult numbers are largely recruitment-limited at low levels of recruitment; but above this other limiting factors are more important in regulating population size (Jones, 1990). It appears that opposing scenarios predicted by the non-equilibrium and resource limitation hypothesis can occur simultaneously in two different areas since adult densities tend to be positively correlated with recruitment densities when recruitment is light, but unrelated when recruitment is heavy (Jones, 1990). It is, therefore important to consider both limiting processes (i.e., competition, predation and other disturbances) as well as demographic parameters (i.e., recruitment, growth and mortality) as possible factors affecting the size and structure of reef fish populations. At any one time, one of these factors may be important, but on a time scale approximate to the longevity of the species studied, no single factor is likely to explain all of the variations observed in the distribution and structure of a population. Since the abundance patterns of juvenile and adult *N. celidotus* observed in Kenepuru and Pelorus Sounds were the reverse of planktonic *N. celidotus* eggs and new recruits it seems that some post-recruitment event in sites in Kenepuru Sound limit populations reaching the potential number of these fish in that area.

Because Jones (1984b) experimentally showed a cause and effect relationship between densities of macro-algae and the abundance of juvenile *N. celidotus* it is possible that the lower levels of macro-algae observed in Kenepuru Sound were indirectly responsible for the lower numbers of 'reef' phase *N. celidotus* observed there. Compared to North Island populations, *N. celidotus* in both Kenepuru and Pelorus Sounds appeared to have a high level of mortality in the 0+ year-class with relatively few fish moving into the 1+ year-class; this was especially true of populations in Kenepuru Sound. *N. celidotus* at this age are partially associated with patches of macro-algae, apparently more so as a source of shelter than food (Jones, 1984a). A lack of shelter and high numbers of conspecifics may have forced many young *N. celidotus* out into the open where they would have found it difficult to feed and have been more vulnerable to predation (Jones, 1984a). Therefore, the paucity of shallow macro-algal habitat may

act as a bottleneck in Kenepuru Sound, limiting the potential number of juvenile and adult *N. celidotus* being reached.

Although comparing only two areas, annual estimates of *N. celidotus* densities made on and around mussel farms in Kenepuru and Pelorus Sounds were inversely related to static estimates of growth observed in fish sampled in these areas. *N. celidotus* living at higher densities in Pelorus Sound were characterised by a significantly lower rate of growth. Recent experimental work has suggested that flexibilities in the growth rates of reef fish can mask competitive interactions for food if competition is measured in terms of mortality (Jones, 1986 and 1987). In terms of growth, food can become the object of competitive interactions at densities below those experiencing mortality. Apparently when food becomes the object of competition among reef fish, due to high densities of conspecifics, fish are forced to feed primarily on lower quality food types that are not as readily transformed into growth of body tissue (Jones, 1986 and 1987; Jones and Norman, 1986).

Static growth estimates from fish sampled and observed in Pelorus Sound were also lower than for *N. celidotus* sampled at Leigh, where densities of  $\geq 1+$  year class fish and growth rates were similar to those observed in Kenepuru Sound. However, the pattern is upset by the comparatively slow growth rates of *N. celidotus* sampled in Wellington. Although densities of  $\geq 1+$  year class fish were higher in Wellington than at either Leigh or Kenepuru Sound, they were less than one seventh of those observed in Pelorus Sound where growth rates were noticeably higher.

Based on these observations it is difficult to explain the magnitude of growth rates solely in terms of the densities observed. However, it remains feasible that the faster growth of adult *N. celidotus* in Kenepuru Sound, as compared to those in Pelorus Sound, is due to the lower densities of conspecifics in that area. The implication here is that *N. celidotus* in Pelorus Sound may be able to maintain the very high densities observed by reducing their growth rates.

Naturally occurring subtidal macro-algae has been shown to be important in the recruitment and development of juvenile *N. celidotus*. However, notable levels of recruitment and developing juveniles were also observed among the encrusting

organisms growing on the mooring ropes of mussel farms. These structures appear to simulate the shallow, macro-algal covered habitat of adjacent natural subtidal areas. Consequently, a small number of *N. celidotus* appear to colonise mussel farms directly by utilising the shelter provided by encrusted mooring ropes rather than migrating onto mussel farms from nearby natural areas. Experimental removal of these encrusting assemblages showed a direct effect on the local abundance of both newly-recruited and developing juvenile *N. celidotus*. The relationship between the encrusting organisms and juvenile *N. celidotus* appears to be linear, since the total removal of encrustations from mooring ropes led to a complete absence of fish and half removal led to about half the number of fish observed on control mooring ropes. Over summer, an accumulation of 0+ and 1+ year-class *N. celidotus* on the mooring blocks associated with stripped mooring ropes indicated that fish migrating from natural, inshore areas may have been stopped from reaching the dropper lines of mussel farms because these mooring ropes had been stripped. This result further suggests that *N. celidotus* not only recruit and develop into the encrustations of mooring ropes, but that inshore migrants also utilise the shelter of these organisms as a pathway to the suspended dropper lines of mussel farms. On the basis of this experiment it is clear that the amount of organic encrustation growing on mooring ropes can directly affect the number of *N. celidotus* recruiting and developing on mussel farms. However, the stripping of mooring ropes alone is unlikely to be an effective means of controlling older juveniles migrating from natural subtidal areas where the bulk of recruitment occurs. These fish simply aggregate around the mooring blocks of mussel farms.

The problem of predation by *N. celidotus* on mussel farms has no simple solution although some good advice is offered by Jenkins (1985) and Meredyth-Young (1985a). Based on the advice of these workers, the results of this study and the many hours that I have spent observing these fish in this artificial habitat I make the following recommendations; used together I hope they may give some relief to the problem of fish predation on mussel farms.

1. Establish new mussel farms in areas of deep water well away from areas of natural dense shallow macro-algae patches. This will restrict the migration of large juveniles from these areas onto mussel farms.
2. Completely strip and keep mooring ropes clear of encrustations. This will restrain the number of planktonic *N. celidotus* recruiting and developing directly on mussel farms. If dropper lines are also kept clear of the benthos then it may reduce the number of *N. celidotus* using the shelter of mooring ropes and dropper lines as a pathway to the mussel crop. Casual observations of these fish showed that they seldom swim through open water and that they stay close to these structures when moving off the benthos. By removing the shelter that these structures afford, fish are more likely to remain on the seabed aggregated around mooring blocks.
3. Use screw-in anchors rather than concrete mooring blocks. Adult *N. celidotus* are significantly correlated with topographic complexity (Jones, 1984c) and densely aggregate around these structures under mussel farms (Clarke, 1993). As mooring blocks are often the only vertical structures under mussel farms, it is less likely that large numbers of *N. celidotus* would build if these structures were not there. Although this needs to be verified experimentally, it is expected that adult *N. celidotus* would be more transient and less associated with mussel farms if these structures were removed.



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## REFERENCES

- Allredge, A.L. and W.M. Hamner (1980).** Recurring aggregation of zooplankton by a tidal current. Est. Coast.Mar. Sci. **10**:31-37.
- Ayling, A.M. and G.W. Cox (1987).** Collins guide to the sea fishes of New Zealand. William Collins Publishers Ltd, Auckland.
- Barlow, G.W. (1981).** Patterns of parental investment, dispersal and size among coral-reef fishes. Env. Biol. Fish. **6**:65-85.
- Barnes, R.D. (1980).** Invertebrate Zoology. Fifth Edition. CBS College Publishing, New York.
- Bradford, J.M., F. Hoe chang, G. Baldwin, B. Chapman, M. Downes and P. Woods. (1987).** Hydrology, plankton, and nutrients in Pelorus Sounds, New Zealand, July 1981 and May 1982. N.Z.J.Mar. Fres. Res. **21**:223-233.
- Bray, R.N., and A.W. Ebeling (1975).** Food, activity, and habitat of three "picker-type" microcarnivorous fishes in the kelp forests off Santa Barbara, California. Fish. Bull. **73**:815-829.
- Bray, T. (1989).** Minitab (version 6.1) Reference Manual. Massey University Computer Centre, Palmerston North.
- Bodkin, J.L. (1988).** Effects of kelp forest removal on associated fish assemblages in central California. J. Expt. Mar. Biol. Ecol. **117**:227-238.
- Brock, V.E. (1954).** A preliminary report on a method of estimating reef fish populations. J. Wildl. Manage. **18**:297-308.
- Butman, C.L. (1987).** Larval settlement of soft-sediment invertebrates: The spatial scales of pattern explained by active habitat selection and the emerging role of hydrodynamical processes. Oceanogr. Mar. Biol. Ann. Rev. **25**:113-165.
- Carr, M.H. (1989).** Effects of macroalgal assemblages on the recruitment of temperate zone reef fishes. J. Exp. Mar. Biol. Ecol. **126**:59-76.
- Carter, L. (1976).** Seston transport and deposition in Pelorus Sound, South Island, New Zealand. N.Z.J.Mar. Fres. Res. **10(2)**:263-282.
- Cassie, R.M. (1955).** Spawning of Snapper, *Chrysophrys auratus* (Forster) in the Hauraki Gulf. Trans. Royal. Soc. N.Z. **84**:309-328.

- 
- Choat, J.H. (1965).** Sexual dimorphism in the labrid fish *Pseudolabrus celidotus* (Bloch and Schneider, 1801). Pacific Sci. **19**:451-457.
- Choat, J.H., and A.M. Ayling (1987).** The relationship between habitat structure and fish faunas on New Zealand reefs. J. Exp. Mar. Biol. Ecol. **110**:257-284.
- Choat, J.H., A.M. Ayling and D.R. Schiel (1988).** Temporal and spatial variation in an island fauna. J. Mar. Biol. Ecol. **121**:91-111.
- Clarke, C.B. (1993).** The association of adult *Notolabrus celidotus* (Pisces: Labridae) within mussel farms in the Marlborough Sounds. MSc thesis. University of Canterbury. Christchurch, New Zealand.
- Cotton, C.A. (1960).** Geomorphology. Seventh Edition. Whitcombe and Tombs, Christchurch. 505 pp.
- Connell, J.H. (1985).** The consequences of variation in initial settlement vs. post-settlement mortality in rocky intertidal communities. J. Exp. Mar. Biol. Ecol. **93**:11-45.
- Connell, S.D. and G.P. Jones (1991).** The influence of habitat complexity on postrecruitment processes in a temperate reef fish population, J. Exp. Mar. Biol. Ecol. **151**:271-294.
- Cowen, R.K. (1985).** Large scale pattern of recruitment by the labrid, *Semicossyphus pulcher*. Causes and implications. J. Mar. Res. **43**:719-742.
- Doherty, P.J. (1983).** Tropical territorial Damselfishes: is density limited by aggression or recruitment. Ecol. **64**(1):176-190.
- Doherty, P.J., D. McB. Williams and P.F. Sale (1985).** The adaptive significance of larval dispersal in coral reef fishes. Env. Biol. Fish. **12**:81-90.
- Doherty, P.F and D. McB. Williams (1988).** The replenishment of coral reef fish populations. Oceanography and Marine Biology: an Annual Review. **26**:487-551.
- Ebersole, J.P. (1985).** Niche separation of two damselfish species by aggression and differential microhabitat utilization. Ecology. **66**:14-20.
- Ebeling, A.W., R.J. Larson, W.S. Alevizon and R.N. Bray (1980).** Annual variability of reef-fish assemblages in kelp forests off Santa Barbara, California. Fish. Bull. **78**(2):361-377.

- 
- Edmonson, W.T. and G.G. Winberg (1971).** A manual of methods for the assessment of secondary productivity in freshwater. In International Biological Programme Handbook 17. Blackwell, Oxford.
- Eggleston, D. (1975).** Determination of age of Kahawai *Arripis trutta* (Bloch & Schneider). N.Z.J. Mar. Fres. Res. **9(3)**:293-298.
- Ehrlich, P.R. (1975).** The population biology of coral reef fishes. Ann. Rev. Ecol. Sys. **6**:211-247.
- Giese, A.C. (1958).** Comparative physiology: annual reproductive cycles of marine invertebrates. Ann. Rev. Physl. **21**:547-76.
- Gonor, J.J. (1972).** Gonad growth in the sea urchin, *Strongylocentrotus purpuratus* (Stimpson) (Echinodermata: Echinoidea), and the assumptions of the gonad index methods. J. Expt. Mar. Biol. Ecol. **10**:89-103.
- Heath, R.A. (1974a).** Physical oceanographic observations in Marlborough Sounds. N.Z.J.Marn. Res. **8**:691-708.
- Heath, R.A. (1976).** Tidal variability of flow and water properties in Pelorus Sound, South Island, New Zealand. N.Z.J.Marn. Fres. Res. **10**:283-300.
- Heath, R.A. (1982).** Temporal variability of the waters of Pelorus Sound, South Island, New Zealand. N.Z.J.Marn. Fres. Res. **16**:95-110.
- Heron, A. C. (1968).** Reviews on zooplankton sampling methods: Plankton gauze. In D.J. Tranter and J. H. Fraser (Editors), *Zooplankton Sampling. Monographs on Oceanographic Methodology 2*. pp.19-26 UNESCO, Paris.
- Hickford, M.J. (1993).** Effects of gill-netting on reef fish populations in central New Zealand. MSc Thesis. University of Canterbury. Christchurch, New Zealand.
- Jenkins, R.J. (1985).** Mussel cultivation in the Marlborough Sounds (New Zealand). Second edition revised by J. Meredyth-Young and G.D. Waught. Fishing Industry Board 77pp.
- Jones, G.P. (1980).** Growth and reproduction in the protogynous hermaphrodite *Pseudolabrus celidotus* (Pisces: Labridae) in New Zealand. Copeia, **4**:660-675.

- 
- Jones, G.P. (1981a). Inter-relationships between ecology, behaviour and life history in the protogynous hermaphrodite *Pseudolabrus celidotus* (Pisces: Labridae). PhD thesis, University of Auckland, Auckland. 120pp.
- Jones, G.P. (1981b). Spawning site choice by female *Pseudolabrus celidotus* (Pisces: Labridae) and its influence on the mating system. Behav. Ecol. Soci. **8**:129-142.
- Jones, G.P. (1983). Relationship between density and behaviour in juvenile *Pseudolabrus celidotus* (Pisces: Labridae). Anim. Behav. **31**:729-735.
- Jones, G.P. (1984a). The influence of habitat and behavioral interactions on the local distribution of the wrasse, *Pseudolabrus celidotus*. Env. Biol. Fish. **10**:43-58.
- Jones, G.P. (1984b). Population ecology of the temperate reef fish *Pseudolabrus celidotus* Bloch & Schneider (Pisces: Labridae). I. Factors influencing recruitment. J. Exp. Mar. Biol. Ecol. **75**:257-276.
- Jones, G.P. (1984c). Population ecology of the temperate reef fish *Pseudolabrus celidotus* Bloch & Schneider (Pisces: Labridae). II. Factors influencing adult density. J. Exp. Mar. Biol. Ecol. **75**:277-303.
- Jones, G.P. (1986). Food availability affects growth in a coral reef fish. Oecologia **70**:136-139.
- Jones, G.P. (1987). Competitive interactions among adults and juveniles in a coral reef fish. Ecology **68**(5):1534-1547.
- Jones, G.P. (1988). Ecology of rocky reef fish of north-eastern New Zealand: a review. N.Z.J.Mar. Fres. Res. **22**:445-462.
- Jones, G.P. (1990). The importance of recruitment to the dynamics of a coral reef fish population. Ecology **71**:1691-1698.
- Jones, G.P. and M.D. Norman (1986). Feeding selectivity in relation to territory size in a herbivorous reef fish. Oecologia **68**:549-556.
- Kingsford, M.J. (1988). The early life history of fish in coastal waters of northern New Zealand: a review. N.Z.J.Mar.Fres.Res. **22**:463-479.
- Kingett, P.D. and J.H. Choat (1981). Analysis of density and distribution patterns in *Chrysophrys auratus* (Pisces: Sparidae) within a reef environment: an experimental approach. Mar. Ecol. Prog. Ser. **5**:283-290.

- 
- Kingsford, M.J. and J.H. Choat (1986).** Influence of surface slicks on the distribution and onshore movements of small fish. Marn. Biol. **91**:161-171.
- Kingsford, M.J., E. Wolanski and J.H. Choat (1991).** Influence of tidally induced fronts and Langmuir circulations on distribution and movements of pre-settlement fishes around a coral reef. Marn. Biol. **109(1)**:167-180.
- Kingsford, M.J. and K.A. Tricklebank (1991).** Ontogeny and behaviour of *Aldrichetta forsteri* (Teleostei: Mugilidae). Copeia **1**:9-16.
- Lagler, K.F., J.E. Bardach and R.R. Miller (1962).** Ichthyology. John Wiley & Sons Inc, New York.
- Lasker, K. (1975).** Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull. **73**:453-63.
- Leum, L.L. and J.H. Choat (1980).** Density and distribution patterns of the temperate marine fish *Cheilodactylus spectabilis* (Cheilodactylidae) in a reef environment. Mar. Biol. **57**:327-337.
- Lobel, P.S. and A.R. Robinson (1986).** Transport and entrapment of fish larvae by mesoscale eddies and currents in Hawaiian waters. Deep Sea Res. **33**:483-500.
- MacDiarmid, A.B. (1981).** Factors influencing the distribution and abundance of two temperate planktivorous reef fish, *Pempheris adspersa* and *Scorpiis violaceus*. Unpublished MSc thesis, University of Auckland. 101pp.
- Meredyth-Young, J. (1985a).** Marine Farming: Mussel farm crop management. Ministry of Agriculture & Fisheries (Information Services). Wellington, N.Z.  
**1/1500/6/85. FX31.**
- Meredyth-Young, J. (1985b).** Marine Farming: Establishing a mussel farm. Ministry of Agriculture & Fisheries (Information Services). Wellington, N.Z.  
**1/1500/6/85. FX32.**

- 
- Mills, K.H. and R.J. Beamish (1980). Comparison of fin-ray and scale age determinations for lake whitefish (*Coregonus clupeaformis*) and their implications for estimates of growth and annual survival. Can. J.Fish. Aquat. Sci. **37**:534-544.
- Ministry of Agriculture & Fisheries (Fisheries Research). (1990). "Fish predation on mussel farms." Nelson, N.Z.
- Mutch, P.G. (1983). Factors influencing the density and distribution of the blue cod (*Paraperca colias*) (Pisces: Mugiloididae). Unpublished MSc thesis, University of Auckland. 73pp.
- McCallum, I.D. (1979). A simple method of taking a subsample of zooplankton. N.Z.J.Marn. Fres. Res. **13(4)**:559-560.
- McCormick, M.I. (1986). Spatial and temporal patterns of abundance *Cheilodactylus spectabilis* (Pisces: Cheilodactylidae). Unpublished MSc thesis, University of Auckland. 113pp.
- McCormick, M.I. and J.H. Choat (1987). Estimating total abundance of a large temperate-reef fish using visual strip-transects. Mar. Biol. **96**:469-478.
- National Institute of Water and Atmospheric Research Ltd (NIWA) Database, Wellington. Telephone communication 1993.
- Norcross, B.L. and R.F. Shaw (1984). Oceanic and estuarine transport of fish eggs and larvae: a review. Trans. Amer. Fish. Soc. **113**:153-165.
- Omori, M., and T. Ikeda (1984). Methods in marine zooplankton ecology. J. Wiley and Sons Inc, New York.
- Orton, J.H. (1920). Sea temperature, breeding and distribution of marine animals. J. Mar. Biol. Assoc. U.K. **12**:339-366.
- Pearce, A.F. and B.F. Phillips (1988). ENSO events, the Leeuwin current, and larval recruitment of the western rock lobster. J. Cons. Int. Explor. Mer. **45**:13-21.
- Purcell, J.E. (1985). Predation on fish eggs and larvae by pelagic cnidarians and ctenophores. Bull. Mar. Sci. **37**:739-55.
- Qasim, S.Z. (1956). Time and duration of the spawning season in some marine teleosts in relation to their distribution. J. Cons. Int. Explor. Mer. **21**:144-155.

- 
- Quast, J.C. (1968).** Some physical aspects of the inshore environment, particularly as it affects kelp-bed fishes. In W.J. North and C.L. Hubbs (editors). Utilization of kelp-bed resources in southern California. Calif. Dep. Fish Game, Bull. **139**:25-34.
- Raven, P.H., R.F. Evert and H. Curtis (1982).** Biology of Plants. Third Edition Worth Publishers Inc, New York. 686pp.
- Robertson, D.A. (1973).** Planktonic eggs and larvae of some New Zealand marine teleosts. PhD thesis, University of Otago, Dunedin. 480pp.
- Robertson, D.A. (1975).** A key to the plankton eggs of some New Zealand marine teleosts. Fish. Res. Div. MAF occasional publication No. 9.
- Robertson, D.R. and S.G. Gaines (1986).** Interference competition structures habitat use in a local assemblage of coral reef surgeonfishes. Ecol. **67**:1372-1383.
- Rosa, M. and M.A. Lee (1920).** A review of the methods of age and growth determination in fishes by means of scales. MAF Fishery Investigations. **Series II., Vol., IV., No. 2.**
- Rice, W.R. (1989).** Analyzing tables of statistical tests. Evol. **43**:223-225.
- Ricker, W.E. (1973).** Linear Regressions in Fishery Research. J. Fish. Res. Board. Can. **30**:409-434.
- Russell, B.C. (1975).** The development and dynamics of a small artificial reef community. Helgoander wiss. Meeresunters. **27**:298-312.
- Russell, B.C. (1977).** Population and standing crop estimates of rocky reef fishes of north-eastern New Zealand. N.Z.J. Mar. Fres. Res. **11(1)**:23-36.
- Russell, B.C. (1988).** Revision of the labrid fish genus *Pseudolabrus* and allied genera. Records of the Australian Museum, Supplement 9. Australian Museum, Sydney. 72pp.
- Russell, B.C., F.H. Talbot, G.R.V. Anderson and B. Goldman (1978).** Research methods. In Coral Reefs, pp.329-345. D.R. Stoddart and R.E. Johannes (Editors) UNESCO, U.K.
- Sale, P.F. (1976).** The effect of territorial adult pomacentrid fishes on the recruitment and survival of juveniles on patches of coral rubble. J. Expt. Mar. Biol.Ecol. **24**:297-306.



- 
- Sale P.F. (1978).** Reef fishes and other vertebrates: a comparison of social structures. In E.S. Reese and Lighter, F.J., (Editors) Contrasts in Behaviour. pp.313-346 Wiley-Interscience, New York.
- Sale, P.F. (1980).** The ecology of fishes on coral reefs. Ann. Rev. Oceangr. Mar. Biol. **18**:367-421.
- Sale, P.F. (1984).** The structure of communities of fish on coral reefs and the merit of a hypothesis-testing manipulative approach to ecology. In D.R. Strong, D.S. Simberloff, L.G. Abele, and A. Thistle, (Editors). pp.478-490 Ecological communities: conceptual issues and the evidence. Princeton University Press, Princeton, New Jersey.
- Sale, P.F. and W.A. Douglas (1981).** Precision and accuracy of visual census technique for fish assemblages on coral patch reefs. Env. Biol. Fish. **6**:333-339.
- Sale, P.F. and B.J. Sharp (1983).** Correction for Bias in Visual Transect Censuses of Coral Reef Fishes. Coral Reefs **2**:37-42.
- Sale, P.F., G.P. Jones, J.H. Choat, J.M. Leis, R.E. Thresher and D. McB. Williams (1985).** Current priorities in ecology of coral reef fishes. Search **16**:270-274.
- Scandol, J.P. and M.K. James (1992).** Hydrodynamics and larval dispersal: a population model of *Acanthaster planci* on the Great Barrier Reef. Aust. J. Mar. Freshwater Res. **43**:583-596.
- Schiel, D.R. (1991).** Coastal biology and the New Zealand Journal of Marine and Freshwater Research, 1967-91. N.Z.J. Mar. Fres. Res. **25**:415-427.
- Shanks, A.L. (1988).** Further support for the hypothesis that internal waves can cause shoreward transport of larval invertebrates and fish. Fish. Bull. **86**:703-714.
- Shanks, A.L. and W.G. Wright (1987).** Internal-wave-mediated shoreward transport of cyprids, megalopae, and gammarids and correlated longshore differences in the settling rate of intertidal barnacles. J. Exp. Mar. Biol. Ecol. **114**:1-13.
- Shenker, J.M. (1988).** Oceanographic associations of neustonic larval and juvenile fishes and dungeness crab megalopae off Oregon. Fish. Bull. **86**:299-317.
- Snedecor, G.W. and William, W.G. (1967).** Statistical Methods. Iowa State University Press, Iowa.

- 
- Sokal, R.R. and F.J. Rolf (1981).** Biometry. Second Edition. W.H. Freeman, San Francisco.
- Solomon, M.E. (1969).** Population Dynamics. The Institute of Biology's Studies in Biology. Number 18. Edward Arnold Ltd. London.
- Southward, A.J. (1955).** Observations on the ciliary currents of the jelly-fish *Aurelia aurita*. J. Mar. Biol. Ass. U.K. 34:201-216.
- Stephens, J.S., R.K. Johnson, G.S. Key and J.E. McCosker (1970).** The comparative ecology of three sympatric species of California blennies of the genus *Hypsoblennius* Gill (Teleostomi, Blennidae). Ecol. Mon. 40:213-233.
- Stephens, J.S. and K.E. Zerba (1981).** Factors affecting fish diversity on a temperate reef. Envr. Biol. Fish. 6:111-121.
- Talbot, F.H., B.C. Russell and G.R.V. Anderson (1978).** Coral reef fish communities: unstable, high diversity systems? Ecol. Mon. 48:425-440.
- Taylor, R.B. (1991).** Effects of *Notolabrus celidotus* (Labridae): Predation on motile macroalgal epifauna. Unpublished MSc Thesis, University of Auckland. 44p.
- Thompson, S. (1979).** Ecological and behavioral factors influencing the distribution and abundance patterns of *Tripterygion varium*. Unpublished MSc thesis, University of Auckland. 80pp.
- Thompson, S.M. and G.P. Jones (1983).** Interspecific territoriality and competition for food between the reef fishes *Fosterygion varium* and *Pseudolabrus celidotus*. Mar. Biol. 76:95-104.
- Thresher, R.E. and J.S. Gunn (1986).** Comparative analysis of visual census techniques for highly mobile reef associated piscivores (Carangidae). Envir. Biol. Fish. 17:93-116.
- Todd, P. (1969)** Age and growth in *Pseudolabrus celidotus* (Bloch and Schneider, 1801) from Wellington Harbour. Unpublished BSc thesis. Victoria University, Wellington.
- Tranter, D. J. and P.E. Smith (1968).** Reviews on zooplankton sampling methods: Filtration performance. In D.J. Tranter and J. H. Fraser (Editors). *Zooplankton Sampling*. pp27-56 Monographs on Oceanographic Methodology 2. UNESCO, Paris.

- 
- Victor, B.C. (1983).** Recruitment and population dynamics of a coral reef fish. Science **219**:419-420.
- Victor, B.C. (1986).** Larval settlement and juvenile mortality in a recruitment-limited coral reef fish populations. Ecol. Mono. **56**:145-160.
- Warner, R.R. (1975).** The reproductive biology of the protogynous hermaphrodite *Pimelometopon pulchrum* (Pisces: Labridae). Fish. Bull. **73**:262-283.
- Webb, R.O. and M.J. Kingsford (1992).** Protogynous hermaphroditism in the half-banded sea perch, *Hypoplectrodes maccullochi* (Serranidae). J. Fish. Biol. **40**:951-961.
- West, G. (1990).** Methods of assessing ovarian development in fishes: a review. Aust. J. Mar. Fres. Res. **41**:199-222.
- Williams, D.McB. (1981).** Dynamics of the pomacentrid community on small patch reefs in One Tree Lagoon (Great Barrier Reef). Bull. Mar. Sci. **30**:159-170.
- Williams, D.McB. and P.F. Sale (1981).** Spatial and temporal patterns of recruitment of juvenile coral reef fishes to coral habitat within One Tree Lagoon, Great Barrier Reef. Biol. **65**:245-254.
- Winer, B.J. (1971).** Statistical principles in experimental design. McGraw-Hill.