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EXECUTIVE SUMMARY

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This report describes the results and management implications of a blue cod tagging and recovery study in Dusky Sound in October 2001 and 2002 respectively.

In October 2001, a tagging programme was undertaken to determine movement patterns and stock mixing rates of blue cod (*Parapercis colias*) within Dusky Sound and the immediate outer coast. Five strata were assigned throughout Dusky Sound, and pots and lines set systematically at 115 sites tagging 4077 blue cod. Rewards were offered and the study was publicised in the popular press. Over the following 17 months 219 tags were returned from both commercial and recreational blue cod fishers although, only 86 of these included sufficiently accurate and meaningful recapture locations to allow descriptions of movement.

Although four blue cod moved over 20 km, including two recaptures in nearby Chalky Inlet, 65% of all blue cod moved less than 1 km from their release site. Movement patterns were not explained by size, sex, strata, or bottom type. Northeast, southeast, and northwest movements were most common, but larger movements were generally eastward into the fiord. Only blue cod from the outermost fiord stratum interacted equally with their seaward neighbours.

One year after tagging, a recovery phase resurveyed 44 randomly chosen sites (6 pots per site = 264 pot lifts) throughout the 5 strata of Dusky Sound. A total of 1515 blue cod were caught, 61 of which were tag recaptures. From these data, a proportional population-mixing model was developed and used to estimate (± 95% CI) the proportion of blue cod populations emigrating from each stratum. The two outermost strata of Dusky Sound drained an annual point estimate of 7.4% (0.1–23.2%) and 9.2% (0.1–26.1%) of their respective populations into the inner half of the fiord which acted as a collecting sink with 100% residency.

These results show that the dynamics of blue cod movements in Dusky Sound are complex. It is because of the overriding site attachment of most blue cod this study supports the potential separate management of fiords as stock units. However, it is important to bear in mind that the source of the inner fiord blue cod stocks appears to be derived from the adjacent open coast.

1. INTRODUCTION

Blue cod (*Parapercis colias*) is a relatively common inshore fish endemic to New Zealand, supporting both significant recreational (about 894 t) and commercial fisheries (about 2316 t) (Annala et al. 2002). Blue cod are not true cod (Family Gadidae), but a rather large sand perch[1] (Family Pinguipedidae), a relatively obscure family of small short ranging coastal fishes spread throughout the Indo-Pacific region (Carbines 2004). New Zealand's most abundant Pinguipedidae, blue cod are widespread but mainly temperate, distributed from the shore to the shelf edge of the entire coastline (Anderson et al. 1998). Found on reef edges, biogenic structures, shingle, gravel, or sand close to rocky outcrops, blue cod are opportunistic benthic carnivores (Jaing & Carbines 2002) seldom ranging more than a couple of kilometres (Mace & Johnston 1983, Carbines & McKenzie 2001). Easily taken by hook (Carbines 1999), blue cod are the species most commonly landed by recreational fishers in the South Island (Bradford 1998, Carbines 1999, James & Unwin 2000). In some accessible areas, like the Marlborough Sounds (Blackwell 2002) and inshore Banks Peninsula (Beentjes & Carbines 2003), patterns of blue cod population size structure and standardised catch rates indicate over fishing has caused areas of local depletion.

A local fisheries management group, the 'Guardians of Fiordland's Fisheries', believe that Fiordland (Figure 1) is increasingly becoming a recreational fishing destination, and as a consequence several fiords (most notably Milford and Doubtful Sounds) no longer support a blue cod fishery of the quality formerly offered. The Guardians also believe that increasing recreational fishing pressure will ultimately lead to the depletion of blue cod in some areas, and this has pre-empted the development of an integrated management strategy for Fiordland's fisheries. To assist them, the Ministry of Fisheries requires details of both relative abundance (see Carbines & Beentjes 2003) and movement patterns of blue cod in the fiords. The scale and directions of movements will ultimately determine the most appropriate scale to apply management actions. For example, if stocks within particular fiords have little or no interaction with those along the outer coast or neighbouring fiords, then the management implications will be quite different than if stocks are mixing with the open coast or even between fiords.

Like other Pinguipedidae (e.g., Stroud 1982, Kobayashi et al. 1993), large male blue cod can be territorial, holding large and rather loose territories (Mutch 1983). In Northland, Mutch (1983) observed the territories of large dominant males (about 1000 m^2) often encompassing those of three to five smaller females (about 250 m^2). Tagging studies in South Island areas also show that while most blue cod are short ranging, a few may travel larger distances (Rapson 1956, Mace & Johnston 1983, Carbines & McKenzie 2001). Two large-scale studies in the Marlborough Sounds (Figure 1) observed that most blue cod moved less than 1 km, but recorded maximum distances of 42 km and 48 km (Rapson 1956, Mace & Johnston 1983). However, both studies suffered high tag loss and low return rates (less than 4%), and no consistent patterns of larger-scale movements were apparent. Also in the Marlborough Sounds, a smaller scale study reported that 73% and 75% of blue cod, tagged in and outside a marine reserve, respectively, had moved less than 100 m (Cole et al. 2000).

In Southland (Figure 1), Carbines & McKenzie (2001) described the large-scale movement patterns and mixing rates of blue cod in terms of current stock boundaries within Quota Management Area (QMA) BCO 5 (about 40000 km^2 of potential blue cod habitat, i.e., area shallower than 200 m). Over 9500 blue cod were tagged throughout Foveaux Strait (statistical area 025 about 4300 km^2, Figure 1) and 8% were recovered after 20 months. The largest distance moved was 156 km, but the median was only 800 m, with 60% moving less than 1 km and a strong trend toward counter-current westward movements. Data from the Ministry of Fisheries catch-per-unit-effort database and commercial fishers logbooks were used to constrain returns due to bias fishing effort. A variation of the Peterson mark-recapture model was used to calculate mixing rates and showed only moderate mixing (7.3% and 14.7% over 20 months) with neighbouring statistical areas (027 and 030) within BCO 5 (Figure 1). However, at a finer

[1] Sometimes also referred to as weevers.

scale, mixing rates were as high as 44% among 14 sub-areas (mean area about 312 37 km^2) within statistical area 025 (Carbines & McKenzie 2001).

Southland blue cod appear to form relatively discrete stocks at a scale most likely below that of a statistical area (about 1000 km^2) and many times smaller than current QMAs (about 10 000 km^2) (see Figure 1). Blue cod are therefore potentially susceptible to local or point depletion within parts of current QMAs, and smaller scale management regimes will be more useful for this species in discrete areas of high fishing pressure. In Fiordland, however, the interactions of blue cod stocks within and between fiords and the outer coastal areas are unknown.

This report describes the results and implications of a blue cod tagging and recovery study in Dusky Sound in October 2001 and 2002. Detail of relative abundance and biological descriptions of catch from October 2002 were presented by Carbines & Beentjes (2003).

2. METHODS

2.1 Study area and design

With the help of several local fishers, all potential blue cod fishing areas throughout and around the mouth of Dusky Sound were identified. To describe the medium scale movement patterns and stock mixing, Dusky Sound was divided transversely into five sequential strata from its head to the immediate open coast (*inner, mid, outer, extreme outer*, and *open coast*) (Figure 2). Strata boundaries were set at a scale that blue cod could potentially form distinct stocks (Mace & Johnston 1983, Carbines & McKenzie 2001) among areas identified by fishers. Within all identified fishing areas, sampling sites were allocated as points at least 300 m apart, and during the tagging phase caught, tagged, and released, over 4000 blue cod in all 115 sites throughout the 5 strata. Tags were recovered from the public for 17 months, and one year post tagging NIWA also led a recovery phase to examine blue cod taken from a randomly selected 44 of the original sites (Figure 3). Carbines & Beentjes (2003) gave detailed biological and catch data from the recovery phase of this study.

2.2 Vessel and gear

Both the tagging and recovery phases of the study were conducted from FV *Solitaire*, a Milford Sound-based commercial vessel equipped to set and lift rock lobster and blue cod pots targeted by sonar and equipped with a GPS. The vessel was chartered by NIWA and skippered by the owner, Mr T. Willetts. To maximise catches during the tagging phase in 2001, up to three fishing methods were be used at each site. Five standard commercial blue cod pots (900 x 500 x 500 mm steel frame covered in 50 mm diameter cyclone wire mesh, with four entrances), two highly modified pots (1200 x 1200 x 500 mm steel frame covered in 20 mm soft synthetic mesh, with four entrances) and up to three hand lines with 6/0 size hooks were used. Both pots and large hooks are known to cause no mortality of returned blue cod, even when handled poorly (Carbines 1999, 2003).

In contrast, during the recovery phase in 2002 fishing was standardised and only six custom designed and built cod pots were used at every site. Pot specifications are: length, 1200 mm; width 900, mm; depth, 500 mm; soft synthetic inner mesh, 30 mm diameter; outer cyclone wire mesh, 50 mm diameter, with four entrances. All pots were numbered, and baited with paua guts.

2.3 Sampling methods

At each site, pots were set and left to fish (soak) for a standardised 1 h during daylight hours. Pots were set in clusters separated by at least 100 m to avoid competing for the same fish. The positioning of pots was determined by the skipper using local knowledge and the vessel sonar to locate suitable areas of light foul within about 150 m of each site. As each pot was set, a record was made of time, pot number, latitude and longitude from GPS, and depth and bottom type from sonar. Pots were lifted aboard using the vessel hydraulic pot lifter, emptied, and the contents sorted by species. After a site was completed the next closest site in the stratum was fished with no allowance made for time of day or tides. Lines were also used opportunistically at sites during the tagging phase only.

2.4 Tagging

In the current study all blue cod were tagged with a 15 mm stemmed yellow (40 mm tail) Hallprint type TBA-2 t-bar anchor fish tags inserted ventrally through the postcleithrum using a Dennison tag-fast III tag gun with No. 08941 needles. All tags were printed with an individual identification number, a contact address, and the words "REWARD (DATE + GPS)". Previous attempts to tag and describe the movements of blue cod have used external tags inserted into dorsal muscle tissue, but return rates were low (3.5%) due to high tag loss (about 43%, Mace & Johnston 1983). Carbines (1998) subsequently evaluated a variety of tag types and found external t-tags inserted ventrally through the base of the pelvic fin significantly reduced tag loss. Carbines & McKenzie (2001) recorded an 8% recovery rate tagging blue cod by this method.

All efforts were made to return fish to the specific area in which they were caught. Pots were therefore set in a systematic manner within 150 m (about 70000 m^2) around each site (Section 2.3). After each pot was lifted, blue cod were quickly removed from pots with wet cotton gloves, and placed in onboard holding tanks fed with running seawater. Fish were then measured to the nearest centimetre below total length, tagged, and placed in a recovery tank. Once all fish had fully recovered (i.e., returned to their normal colour) they were released at the centre of each fishing area and the release site was recorded by GPS (see Figure 2). One mass central release at the centre of a constrained fishing area meant that a) blue cod were released no further than about 150 m from their point of capture; b) all blue cod had sufficient time to recover from tagging; and c) losses from predators such as mollymawks (*Diomedea* sp.) and barracouta (*Thyrsites atun*) were avoided.

To encourage tag returns from the public, a reward t-shirt was offered and articles on the tagging programme were published in several relevant magazines and newspapers (Anon 2002a, 2002b, 2002c, 2002d, Carbines 2002).

2.5 Recovery phase

One year after the tagging phase was completed a potting survey was done to recover tagged blue cod for a fisheries independent stock-mixing model (Appendix 1), and to estimate relative abundance (see Carbines & Beentjes 2003). The survey used a two-phase stratified random station design (Francis 1984), adapted from the standard application for trawl surveys to allow for the use of pots. The 115 sites of the October 2001 tagging survey were all used as potential stations for the potting survey in October 2002. Ensuring that sites were at least 300 m apart, stations were allocated randomly for phase 1 (38) and 2 (6) of the survey. Allocation of phase 2 stations to strata was carried out near the completion of phase 1 based on the mean catch rate (kg per pot per hour) of all blue cod per stratum and optimised using the 'area mean squared' method of Francis (1984).

2.6 Data analysis

The net distance travelled by blue cod was calculated as the straight-line distance between release and recapture GPS locations. Only occasionally did the calculated route intersect land, where distance travelled was then estimated by a series of seaward straight lines. For estimates of direction moved, intersection with land was ignored. The magnitude and direction of movement recorded from each stratum was presented graphically.

Two separate single-factor randomisation tests (Manly & Francis 1999) were used to investigate the separate effects of strata and habitat at release on the distance moved. The Manly & Francis test uses a randomisation procedure to approximate the F distribution used in the analogous parametric analysis of variance test (ANOVA). Unlike the standard ANOVA, the Manly & Francis procedure is not biased by the presence of unequal variances in the data.

One obvious problem in the analysis of tag recoveries is variation in fishing effort between areas. To compensate for this, recoveries per-unit-effort are used rather than total recoveries. In the current study, five tagging strata with detailed estimates of catch and effort from the recovery phase were used in a modification of the Petersen mark-recapture model to estimate mixing rates (see Appendix 1). Using results from the recovery phase, a variation of the Peterson model was developed based on assumptions not violated by this data set (see Appendix 1). The model was able to point estimate the proportion of the blue cod population moving inwards from four innermost strata. Confidence intervals (95%) were bootstrapped from 1000 simulations.

3. RESULTS

3.1 Tag and release phase

From 11 to 17 October 2001, 4077 blue cod were tagged and released from 115 sites (Figure 2, Table 1). At least 500 fish were tagged in each stratum, but large variations in catch rates and fishable areas made it possible to tag considerably more in the *open coast* and *extreme outer* strata (Table 1). The average depth fished was 32.5 m, and ranged from a maximum of 88 m in the *extreme outer* stratum to 4 m in the *inner* stratum (Table 1). In the *open coast* and *extreme outer* strata, blue cod were taken mainly from light foul surrounding larger boulders or rocky headlands, but within Dusky Sound blue cod came from a shallow and frequently narrow ledge of flat light foul extending out from the often steeply sloping shore. No blue cod were caught along submerged cliff faces or in deep trenches, highlighting the importance of flat areas of shallow light foul habitat for blue cod in the fiords.

Although not standardised in the release phase, catch rates were notably higher in the *open coast* stratum, and diminished with increased penetration into the fiord. Tagged fish ranged from 14.5 to 61.5 cm total length, with the mean ranging from 37.4 cm in the *middle* stratum to 39.5 cm in the *inner* stratum (Table 1). Length frequency distributions in all five strata were similar, and were characterised by a strong mode at about 38.0 cm (Figure 4). There was a tendency for the inner strata (*inner, mid,* and *outer*) to have proportionally more small blue cod (under 30.0 cm) than the outer strata (*extreme outer* and *open coast*). Larger blue cod (over 50.0 cm) were also better represented in the two inner most strata (*inner* and *mid*) as well as the *extreme outer* stratum. However, the distribution for all strata combined was symmetrical.

3.2 Recovery phase

Between 15 and 26 October 2002, 1515 blue cod (of which 61 were tagged) were taken from 44 of the original 115 sites selected randomly within strata (Table 2, Figure 3). Using six standardised pots (see Sections 2.3) at each of the 44 sites (6 pots set per site = 264 pot lifts), a total of 1004 kg of catch was taken, of which 873 kg (87%) was blue cod. Catch rates of blue cod averaged 2.69 ± 0.17 kg per pot per hour, and ranged from 1.28 kg per pot per hour in stratum *mid* to 8.42 kg per pot per hour for stratum *open coast*, tending to diminish with increasing penetration into the fiord (Table 2).

Length frequency distributions for the four strata within Dusky Sound were similar, but lacked clear modes (Figure 5). In contrast, stratum *open coast* showed a clear mode at about 33.0 cm, with few fish less than 25.0 cm. In all strata the largest blue cod were males, and, on average, males were larger than females. The overall sex ratio was skewed in favour of females at 0.78:1 (male: female), and only stratum *outer* had more males than females (1.5:1). A detailed discussion of biological data and strata catch rates from the recovery phase was given by Carbines & Beentjes (2003).

The 61 recovered tagged blue cod ranged from 24.0 to 51.5 cm at tagging. Both the number of returns and return rates varied greatly among strata, most coming from the *inner* stratum (19 – 3%) and least from the *mid* stratum (4–0.007%). The mean (0.77–3.91 km) and median (0.33–1.08 km) distances moved also varied among strata (Table 2), as did the maximum distances moved (3.94–30.17 km). Only three blue cod moved out of their release strata, two to neighbouring strata (*extreme outer* to *outer*), and one across two strata (*outer* to *inner*; Table 3 & Figure 6). However, there was 29–75% movement between sites within the five strata (see Table 2).

3.3 Stock mixing rates between strata

The stock mixing model assumption of 100% residency in the inner half of the fiord (*inner* & *mid* strata combined) was true for both recovery phase and public returns (Table 4). Over a 1-year period, residency was 93.8% (95% CI 75.7–99.9%) in the *outer* stratum, and 90.7% (74.3–99.9%) in the *extreme outer* stratum, equivalent to population losses to the inner fiord of 6.2% and 9.3% respectively.

3.4 Tag returns from the public

From 1 November 2001 to 31 March 2003 (17 months), 219 tags were returned from commercial and recreational fishers (Table 5), bringing the total return rate to 6.87%. These fish ranged from 29.0 to 61.5 cm at tagging. However, only 86 (39%) of these tag returns contained meaningful recapture locations and could subsequently be used to derive movement statistics (Table 5). The mean (0.77–3.91 km) and median (0.33–1.08 km) distances moved also varied amongst strata, as too did the maximum distances (3.94–30.17 km). Most movement was recorded in the *extreme outer* stratum, and least in the *inner* stratum (Table 5). Both return rates and the number of returns also varied among strata, by far most coming from the *open coast* stratum (9.49%, n = 107), and least from the *inner* stratum (1.91%, n = 12), the opposite result to the recovery phase in which the distribution of effort was balanced (Section 3.2).

Using the ratios of all public to NIWA tag returns, multiplied by the amount of NIWA effort in each strata, it is possible to estimate the amount of public fishing effort (in terms of standardised NIWA pot sets) expected to catch those tags returned from each stratum (Table 6). This model suggests the equivalent of 900 1 h NIWA pot sets would have been required to catch the 219 public tag returns in the way they were distributed over strata of Dusky Sound. It also appears that public fishing effort was highly skewed, with almost half located in the *open coast* stratum and only 3% in the *inner* stratum (Table 6).

3.5 Distance and direction moved

Although 4 blue cod moved over 20 km, including 2 recaptured in Chalky Inlet (more than 30 km by sea), 65% of the 147 blue cod for which distance moved could be confidently calculated had moved less than 1 km from their release site (Figure 8). Neither size nor sex appeared to have any bearing on distance moved (Figure 9).

During the recovery phase only three tagged fish moved between strata (4.9%; Table 3), all of them inward (i.e., away from the mouth) (see Figure 6). However, when combined with the public returns, the proportion of blue cod that crossed strata boundaries was greatly increased (13.8%; Table 4 & Figure 7). Although recoveries from the public confirmed the pattern of inward dominated strata movements observed during the recovery phase (see Tables 2 & 3), these also revealed some two-way interaction between the most seaward strata (*open coast & extreme outer*), restricting the assumption of exclusive inward movement (Appendix 1) to only the three innermost strata (see Table 4 & 5). Details of site movements could not be determined for public returned tags.

Within all strata the direction of movement was consistent between recovery phase (Figure 8) and public returns (Tables 7 & 8), but more medium scale movements were apparent among the public returns (Figures 10 & 11). Northeast, southeast, and northwest movements were more common, but larger movements were generally eastward, with some westward movements from the *extreme outer* strata and southern movement of two fish recovered in Chalky Inlet (Figure 11).

Two separate single-factor randomisation tests (Manly & Francis 1999) were used to investigate the separate effects of strata and habitat at release on the distance moved; both results were non-significant ($p = 0.35$ and $p = 0.16$ respectively).

4. DISCUSSION

The results of this study provide the first movement and stock mixing data for blue cod in Fiordland. Although most tagged blue cod had moved less than 1 km, there was a strong bias toward inward movements. No fish were observed moving seawards from any of the inner three strata, with reciprocal mixing observed only between the *open coast* and *extreme outer* strata. This west-east trend could not be explained by spatial differences in fishing pressure, which appeared to be greatest in the outermost strata. Mixing rate calculations showed how blue cod in Dusky Sound mixed only moderately among strata, and confirmed that movement was generally inward. However, no statistically significant differences in the distance moved between strata were detected. The proportional population-mixing model suggests the inner half of Dusky Sound is a sink, and the outer half and open coast populations are more mobile and interactive, but still drain into the inner fiord. Loss or movement of blue cod from Dusky Sound to other fiords was recorded only from the two outermost strata.

The tagging results suggest that movement of blue cod into fiords such as Dusky Sound is likely to be slow, and hence if fishing pressure is disproportionate to stock abundance and immigration rates it will deplete areas of blue cod. Movement of blue cod within Dusky Sound is complex, and broader scale stock movement processes possibly drove the movement patterns observed. However, it is clear that the three innermost strata acted as sinks, collecting close to 10% of fish from the outer sound. Freshwater surface currents flow from east to west in Dusky Sound, and inward movements of blue cod may play crucial roles in the larval recruitment process by countering the effects of these currents (Harden Jones 1968, Booth 1997). However, fiord current regimes are complex (e.g., Pickrill 1987), and a dedicated study of Dusky Sound ichthyoplankton would be required to elucidate blue cod population dynamics in the planktonic, settlement, and recruitment life phases.

Several studies have shown how the distribution of ichthyoplankton can determine the distributions of newly recruited juvenile reef fish (Barlow 1981, Stephens & Zerba 1981, Victor 1983, 1986, Kingsford & Choat 1986, Kingsford 1988). 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). However, other mechanisms may be involved in planktonic stock retention in Dusky Sound, such as eddies which trap larvae in the lee of islands and shallow reefs, retaining them long enough to settle. Several studies have highlighted the importance of local eddies in maintaining stock densities

(Cowen 1985, Chiswell & Roemmich 1998, Chiswell & Booth 1999), 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).

Both Rapson (1956) and Mace & Johnston (1983) have suggested that movements of blue cod are size-dependent, although Rapson (1956) considered that larger fish were most mobile, Mace & Johnston (1983) concluded it was generally smaller fish that moved. No size-distance relationship was evident in the current study. In Foveaux Strait, the habitat that blue cod were released into had no apparent effect on distance moved, whereas tagging location was an important but complex factor influencing distance travelled (Carbines & McKenzie 2001). In Dusky Sound, neither habitat nor release location had any significant effect on the distance moved.

In 1956, Rapson found that of 191 recovered blue cod tagged in the Marlborough Sounds, 9.3% had moved more than 1.6 km, and only 3.1% had moved more than 16 km. Twenty-seven years later, Mace & Johnston (1983) found considerably more movement among 84 blue cod tagged throughout the Marlborough Sounds (25.0% over 1.6 km, and 4.8% over 16 km). At the opposite end of the South Island, in Foveaux Strait, Carbines & McKenzie (2001) found 29.1% of the 743 returned tagged blue cod had moved more than 1.6 km, consistent with Mace & Johnston's (1983) findings (Table 9). However, Mace & Johnston (1983) reported that only 4.8% of their recaptured animals had moved more than 16 km, whereas, in the Foveaux Strait study 11.0% had moved more than this. These results suggest that aggregations of blue cod in the unsheltered coastal waters of Foveaux Strait have comparable temporal stability to those in the sheltered enclosed waters of the Marlborough Sounds. However, the mobile portion of the Foveaux Strait population moved greater distances than the mobile portion of the Marlborough Sounds population (Table 9). In Dusky Sound, 25.5% of tagged fish had moved more than 1.6 km, but only 3.5% moved more than 16 km (Table 9). The recurring conclusion of these studies is the potential to manage blue cod on smaller spatial scales than is done currently, especially in sheltered and enclosed areas. The results presented here indicate that blue cod is a species more suited to local scale management than the large-scale management of the Quota Management System (see Annala et al. 2000). Such local management strategies as taiapure (Ministry of Agriculture & Fisheries 1993), mataitai (Ministry of Agriculture & Fisheries 1993, Ministry of Fisheries 1998) and marine reserves (Department of Conservation 2000) are likely to benefit blue cod, but only if the areas they cover are large enough to encompass a resident population. While the required size of such areas will vary between locations, the minimal area would be at least 4 km^2.

The Paterson Inlet Management Plan (Stewart Island) (Elvy et al. 1997) covers 96 km^2, and is a good example of a more appropriate scale for the management of southern blue cod. Blue cod size (Davidson 1995) and movements (Cole et al. 2000), both in and outside the Long Island-Kokomohua Marine Reserve (6 km^2) in the Marlborough Sounds, also suggest that an area of this size can effectively hold a resident population. As long as a small-scale management plan is large enough to maintain a resident population for several years, then both this and other studies (Rapson 1956, Mace & Johnston 1983, Davidson 1995, Cole et al. 2000, Carbines & McKenzie 2001) suggest they will be effective management tools to enhance blue cod populations. However, more research on the effects that these areas have on localised blue cod populations in several regions would be helpful in confirming the effectiveness of such management regimes.

In summary, the results of the current study show that the dynamics of blue cod movements in a fiord are complex. However, because of the overriding site attachment of most blue cod, this study supports the potential separate management of fiords as separate stock units. However, it is important to bear in mind that the source of the inner fiord blue cod stocks appears to be from their adjacent open coast.

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Table 1: Number of sites and blue cod tagged in strata (see Figure 2).

Strata	No. Sites	No. tagged	Depth range (m)	Mean size (cm)
Open coast (oc)	15	1117	26–82	38.5
Extreme outer (eo)	25	1081	13–88	39.0
Outer (out)	21	696	8–81	37.6
Middle (mid)	31	556	5–51	37.4
Inner (inn)	23	627	4–27	39.5
Total	115	4077	4–88	38.5

Table 2: Recovery phase statistics. Numbers in brackets are standard errors of the mean or number of fish. The direction of percentage fish crossing strata boundaries is marked + for *inward movements*.

Strata	Sites	Examined	Recaptures	Depth range (m)	Mean CPUE (kg/pot/h)	Mean size (cm)	Crossed strata	Moved sites	Mean dist (km)	Median dist (km)	Dist range (km)
Open coast (oc)	6	485	12	33–82	8.4 (1.5)	35.9 (0.3)	0	58% (7)	0.5 (0.1)	0.49	0.0–1.4
Extreme outer (eo)	8	295	12	13–82	3.2 (0.4)	37.3 (0.4)	+17% (2)	58% (7)	1.0 (0.3)	0.30	0.0–8.1
Outer (out)	14	401	14	5–62	2.6 (0.4)	37.9 (0.3)	+7% (1)	29% (4)	1.7 (0.6)	0.45	0.1–17.2
Middle (mid)	8	132	4	4–33	1.3 (0.2)	32.9 (0.5)	0	75% (3)	1.1 (0.2)	0.76	0.0–2.7
Inner (inn)	8	202	19	5–18	2.9 (0.3)	40.3 (0.6)	0	37% (7)	0.3 (0.1)	0.26	0.1–2.0
Total	44	1515	61	4–82	2.7 (0.2)	37.8 (0.4)	5% (3)	46% (28)	0.9 (0.3)	0.34	0.0–17.2

Table 3: Recovery phase strata movements (n = *61*). For *abbreviations*, see Table 1.

Release\recapture strata	oc	eo	out	mid	inn
Open Coast (oc)	12	0	0	0	0
Extreme Outer (eo)	0	10	2	0	0
Outer (out)	0	0	13	0	1
Middle (mid)	0	0	0	4	0
Inner (inn)	0	0	0	0	19

Table 4: Total recaptures strata movements (n = 147). For abbreviations, see Table 1.

Release\recapture strata	Chalky	oc	eo	out	mid	inn
Open coast (oc)	1	34	5	1	0	0
Extreme outer (eo)	1	5	31	5	0	0
Outer (out)	0	0	0	25	0	1
Middle (mid)	0	0	0	0	11	1
Inner (inn)	0	0	0	0	0	26

Table 5: Total recapture statistics. Numbers in brackets are standard errors of the mean. The direction of percentage fish crossing strata boundaries is marked + for inward movements and – for outward movements.

Strata	Total Returns	Public Returns	Returns + GPS	Mean size (cm)	Crossed strata - outward :+ inward	Mean dist (km)	Median dist (km)	Dist range (km)
Open coast (oc)	118	107	41	39.4 (0.9)	-2.4% (1):+14.6% (6)	2.47 (0.82)	0.57	0.00–29.61
Extreme outer (eo)	59	47	42	41.2 (1.1)	-14.3% (6):+11.9% (5)	3.91 (1.03)	1.08	0.02–30.17
Outer (out)	50	38	26	38.8 (0.9)	+3.8% (1)	2.39 (0.91)	0.45	0.10–17.22
Middle (mid)	19	15	12	36.8 (1.7)	+9.1% (1)	2,57 (1.81)	0.57	0.04–20.12
Inner (inn)	31	12	26	40.2 (1.1)	0	0.77 (0.19)	0.33	0.08–3.94
Total	277	219	147	39.8 (0.5)	13.8% (20)	2.58 (0.44)	0.57	0.00–30.17

Table 6: Estimate of public fishing effort in NIWA pot units.

Strata	Recaptures Public	Recaptures NIWA	Recaptures Ratio	Pots NIWA	Estimated public effort (NIWA pots sets)	
Open coast (oc)	107	12	8.9	48	428	47%
Extreme outer (eo)	47	12	3.9	48	188	21%
Outer (out)	38	14	2.7	84	228	25%
Middle (mid)	15	4	3.8	48	180	20%
Inner (inn)	12	19	0.6	48	30	3%
Total	219	61	3.6	252	905	100%

Table 7: Recovery phase recaptures, given as compass direction of movements (n = 61).

Strata	N	NE	E	SE	S	W	NW	Total
Open coast (oc)	0	2	0	3	1	0	6	12
Extreme outer (eo)	0	7	0	5	0	0	0	12
Outer (out)	0	6	2	5	0	0	1	14
Middle (mid)	0	3	0	1	0	0	0	4
Inner (inn)	0	9	0	2	0	3	5	19
Total	0	27	2	16	1	3	12	61

Table 8: Total recaptures, given as compass direction of movements (n = 145).

Strata	N	NE	E	SE	S	W	NW	Total
Open coast (oc)	0	10	0	21	1	0	9	41
Extreme outer (eo)	0	12	0	20	0	0	10	42
Outer (out)	0	9	2	12	0	0	2	25
Middle (mid)	0	4	0	3	0	0	4	11
Inner (inn)	0	11	0	4	0	3	8	26
Total	0	46	2	60	1	3	33	145

Table 9: Summary of large-scale blue cod tagging study statistics.

	Tagged	Recaptures	Duration	Max distance (km)	Over 1.6 km	Over 16 km
Pelorus Sound Marlborough Sounds (Rapson 1956)	5050	191 (3.8%)	13 months (1940–41)	48	9.3%	3.1%
Pelorus & Queen Charlotte Marlborough Sounds (Mace & Johnston 1983)	2430	84 (3.5%)	28 months (1973–76)	42	25.0%	4.8%
Foveaux Strait Southland (Carbines & McKenzie 2001)	9368	743 (7.9%)	20 months (1998–1999)	156	29.0%	11.0%
Dusky Sound Fiordland (Carbines & McKenzie 2004)	4077	277 (6.8%)	17 months (2001–2002)	30	25.5%	3.5%

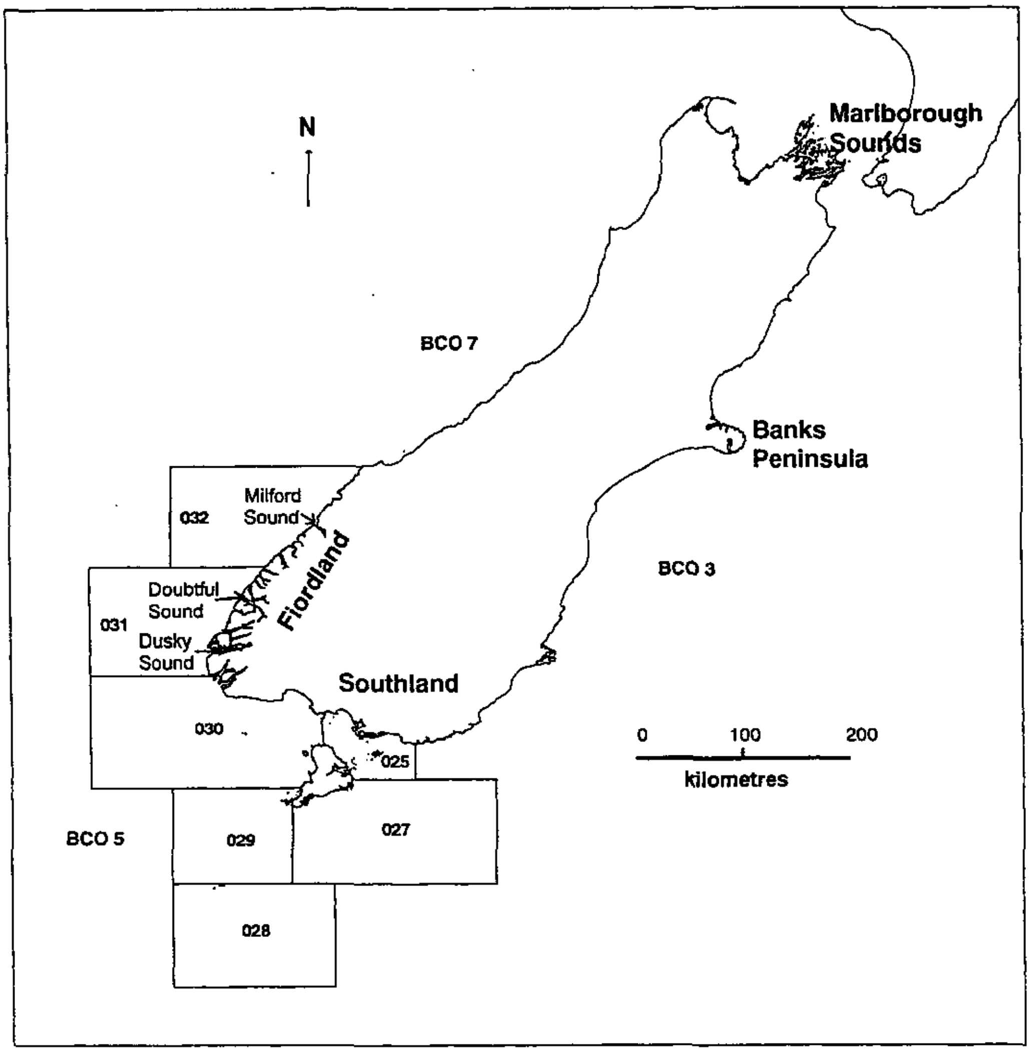


Figure 1: South Island blue cod Quota Management Areas BCO 3, BCO 5, and BCO 7. The seven statistical areas of BCO 5, including statistical area 025 (Foveaux Strait), are also shown. The study area, Dusky Sound, is located within statistical area 031 of Quota Management Area BCO 5.

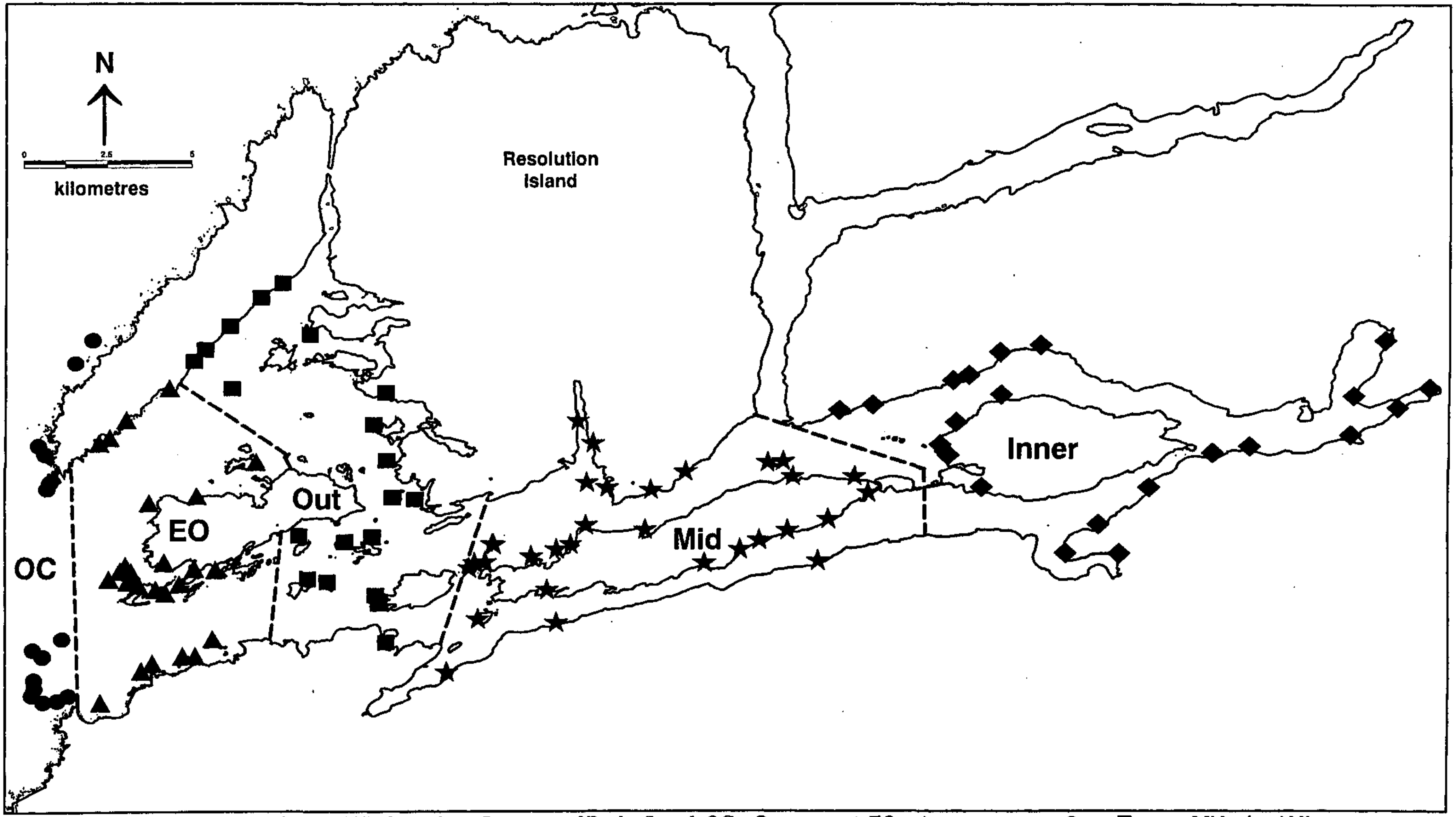


Figure 2: The location of release sites (n=115) throughout five strata of Dusky Sound. OC – ● open coast, EO – ▲ extreme outer, Out – ■ outer, Mid – ★ middle, Inner – ◆. For further details by strata see Table 1.

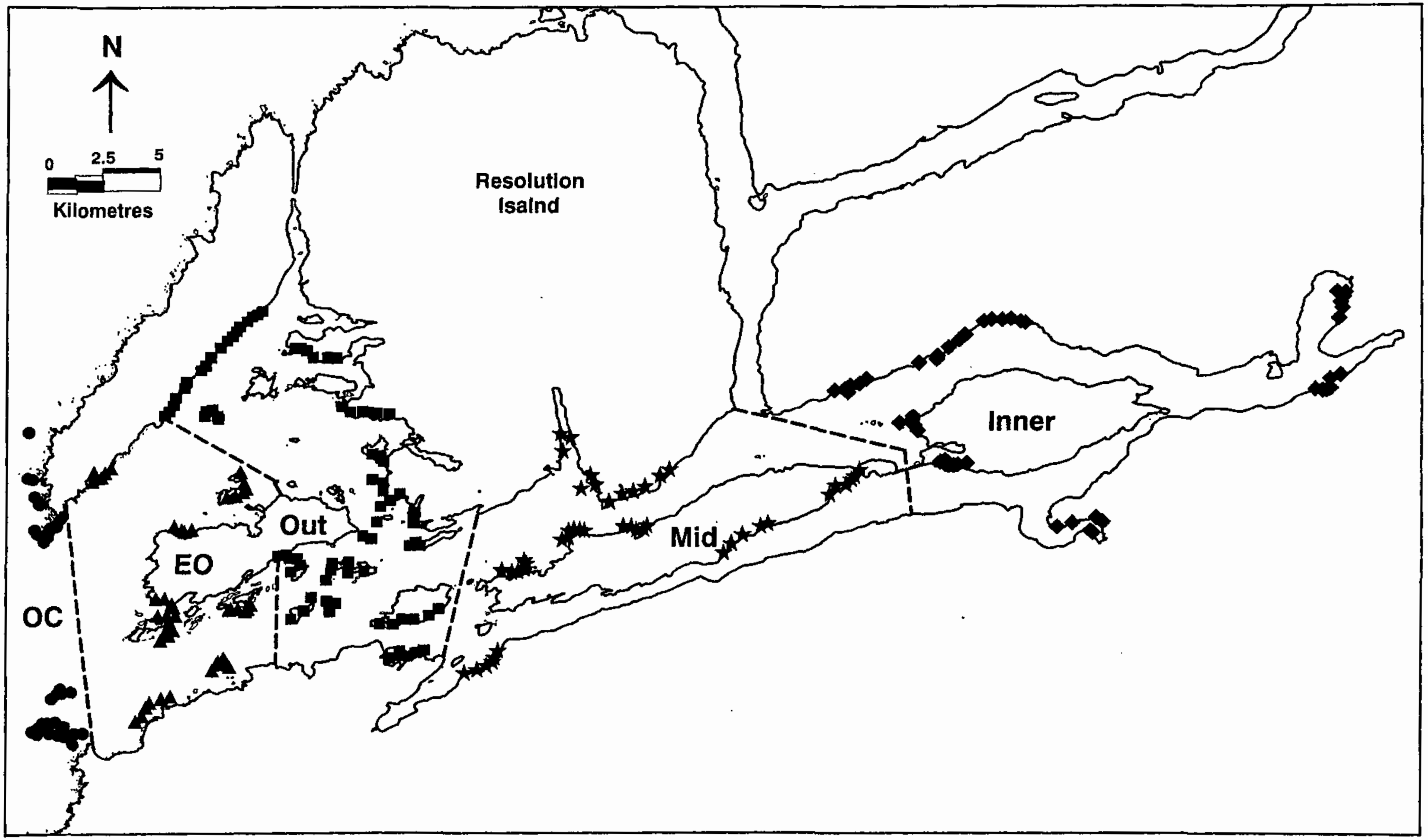


Figure 3: The location of pots set in recovery phase sites surveyed (44 sites, 6 pots set per site = 264 pot lifts) throughout five strata of Dusky Sound. OC – ● open coast, EO – ▲ extreme outer, Out – ■ outer, Mid –★ middle, Inner – ◆.

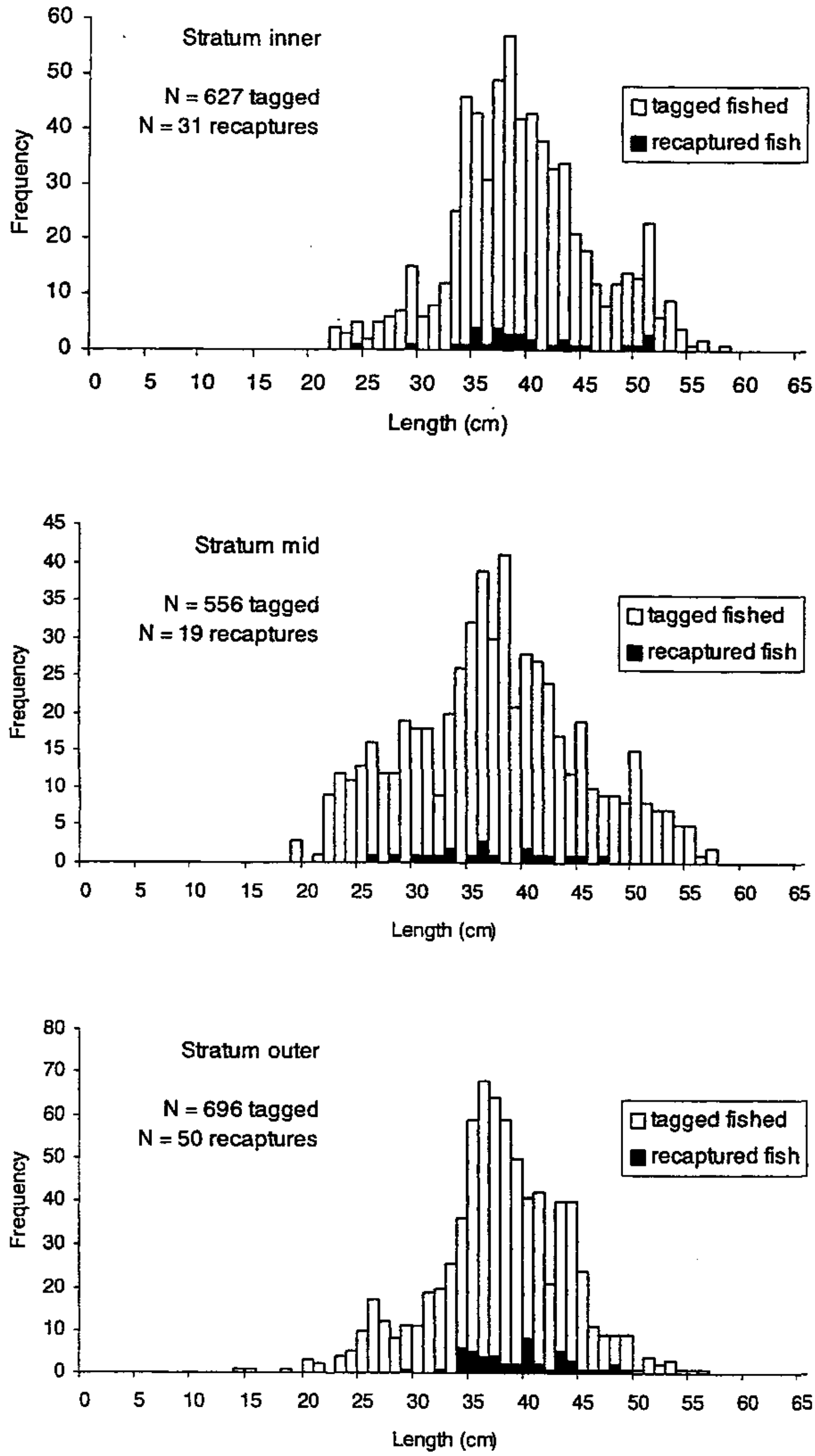
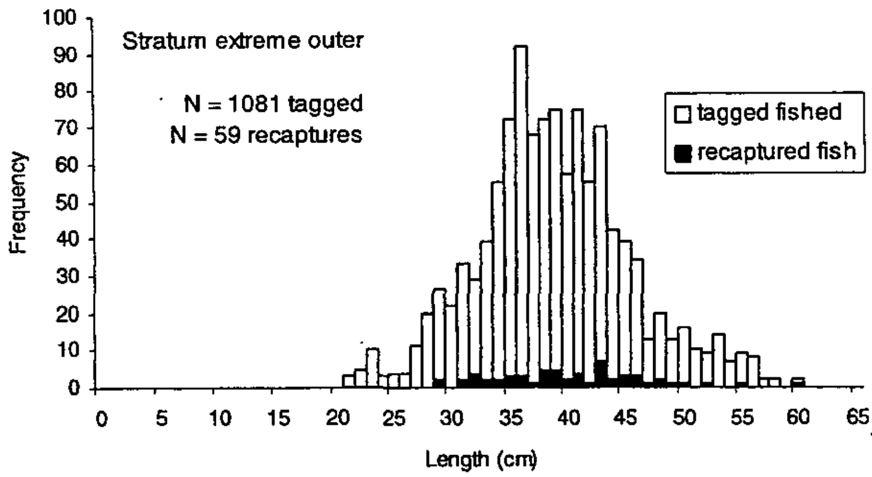
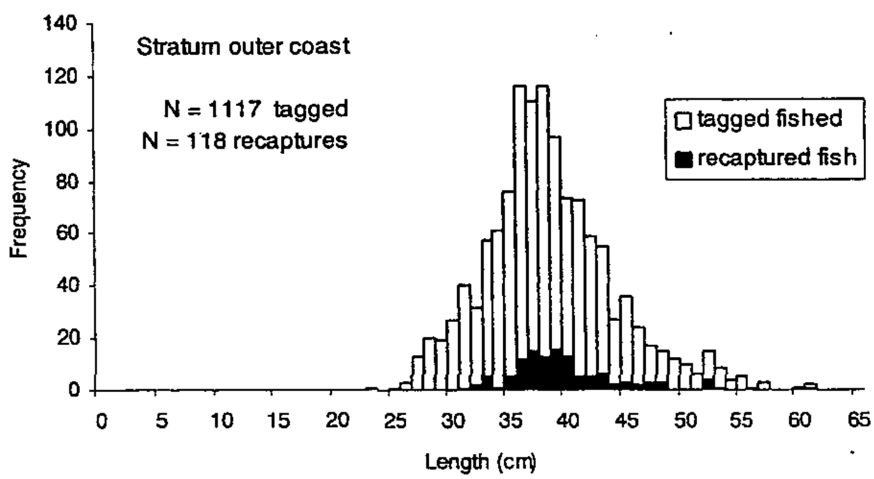


Figure 4: Length frequency distributions of tagging phase blue cod for each stratum and for all strata combined and all recoveries combined.





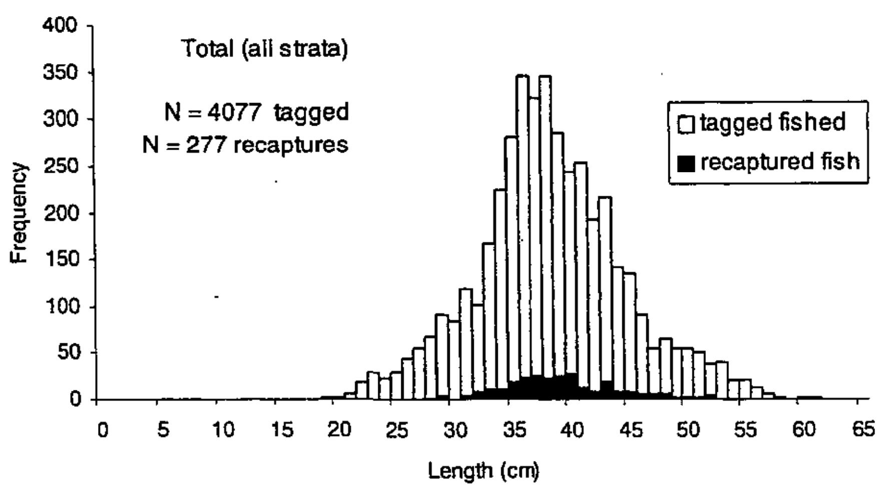


Figure 4 – ***continued***

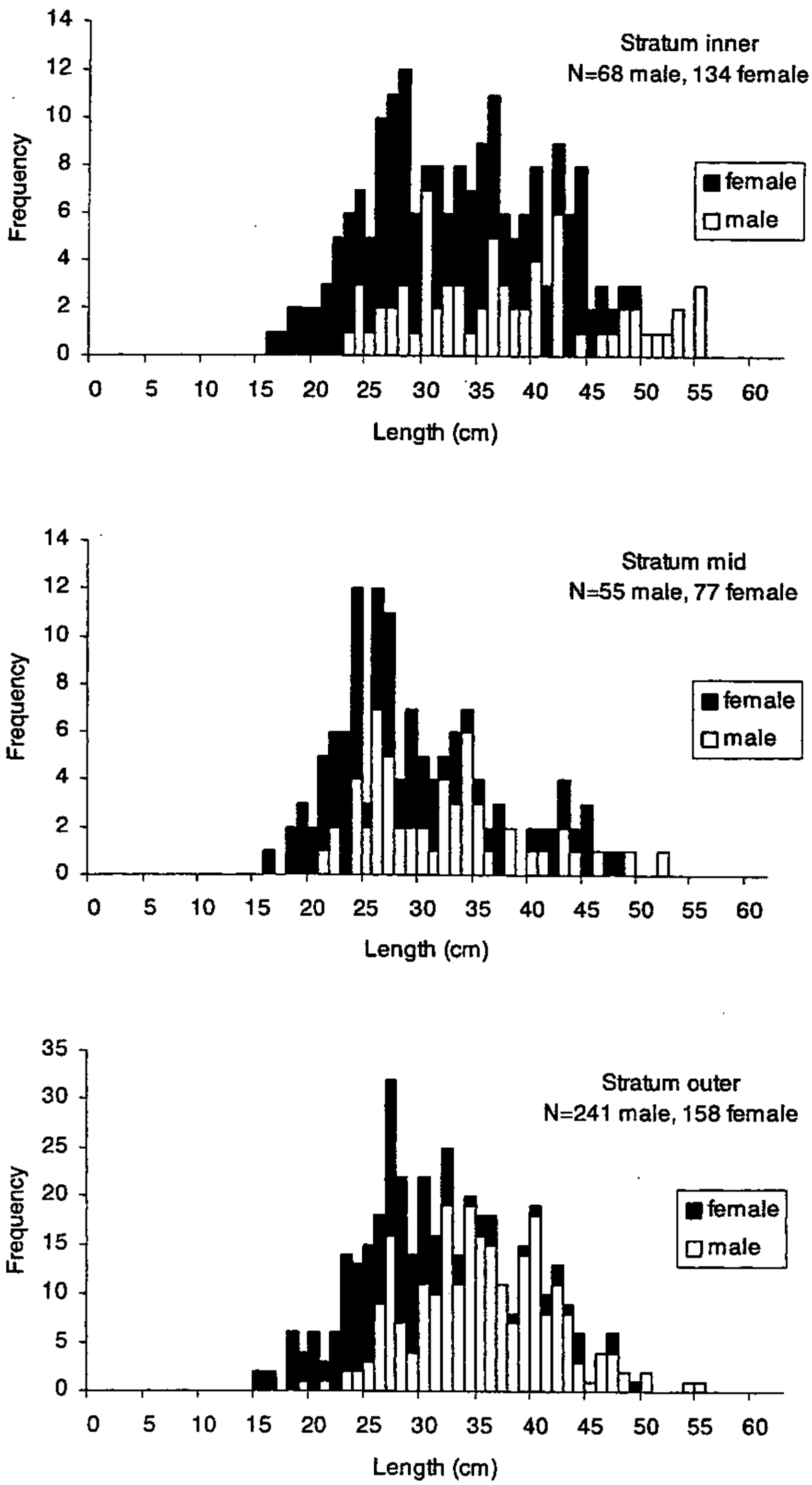


Figure 5: Length frequency distributions of recovery phase blue cod for each stratum and for all strata combined.

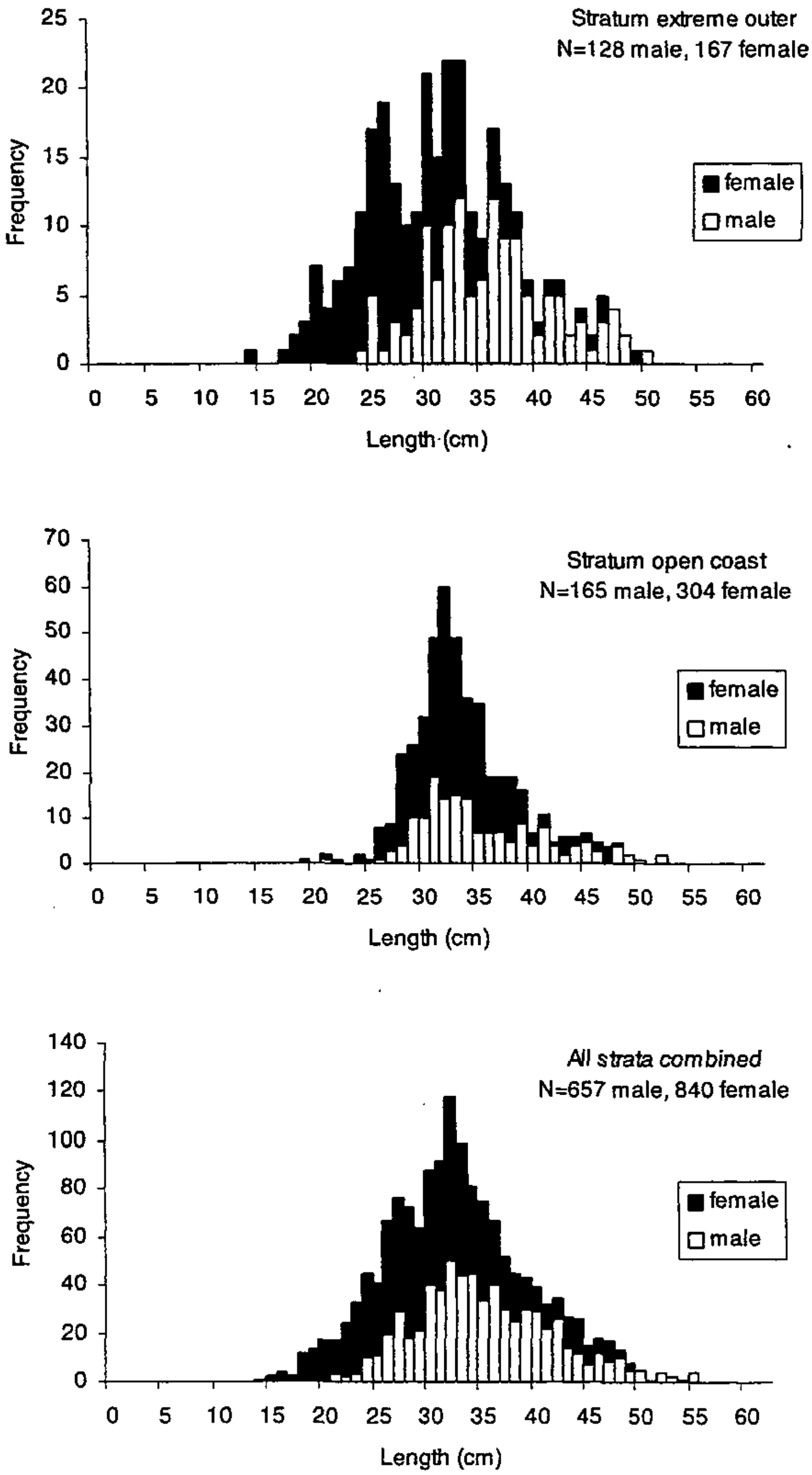


Figure 5 – ***continued***

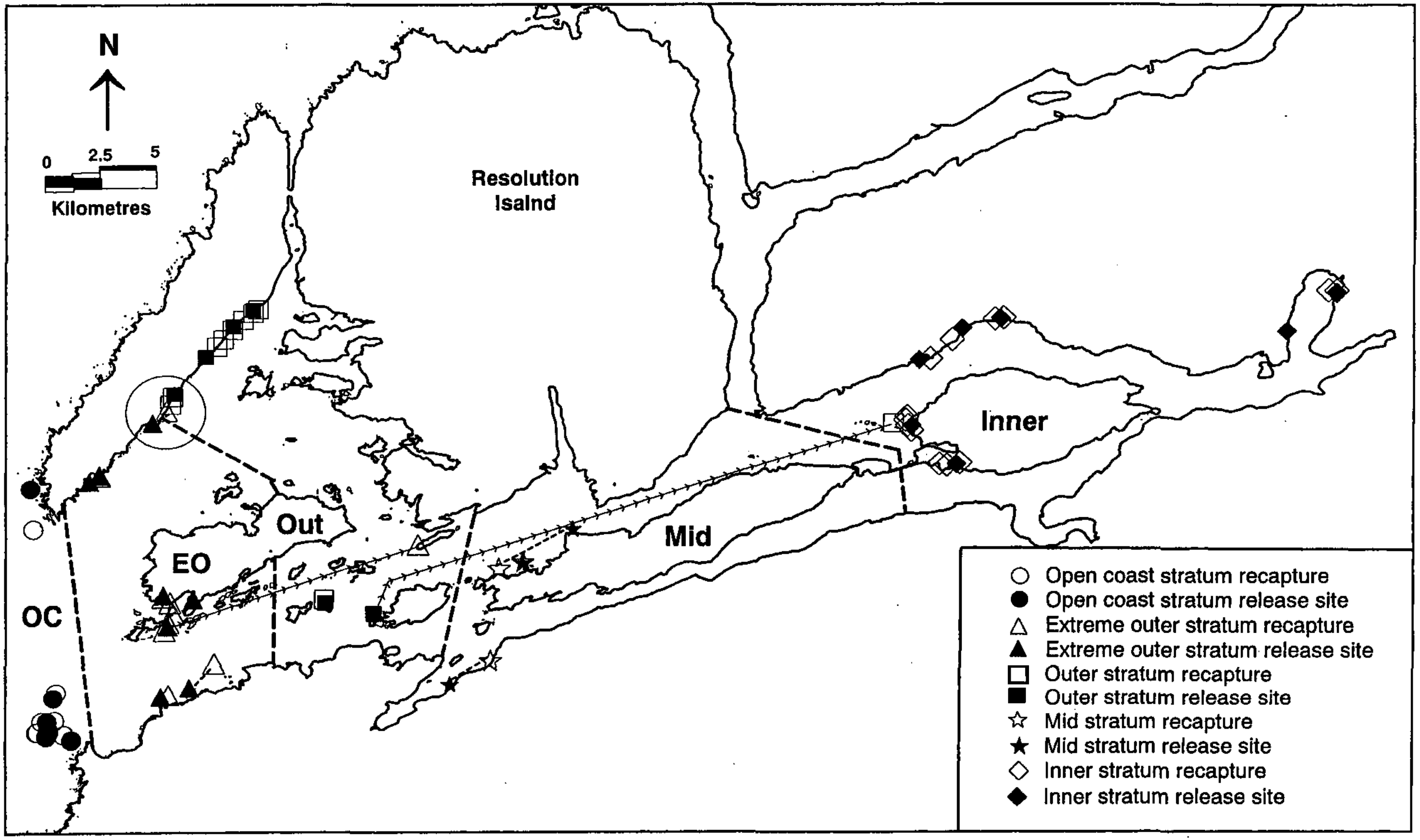


Figure 6: The location of release (solid symbols) and recovery (open symbols) sites of blue cod caught during the recovery phase throughout five strata of Dusky Sound (n=61). OC – ● open coast, EO – ▲ extreme outer, Out – ■ outer, Mid –★ middle, Inner – ◆. The three movements to cross strata are marked.

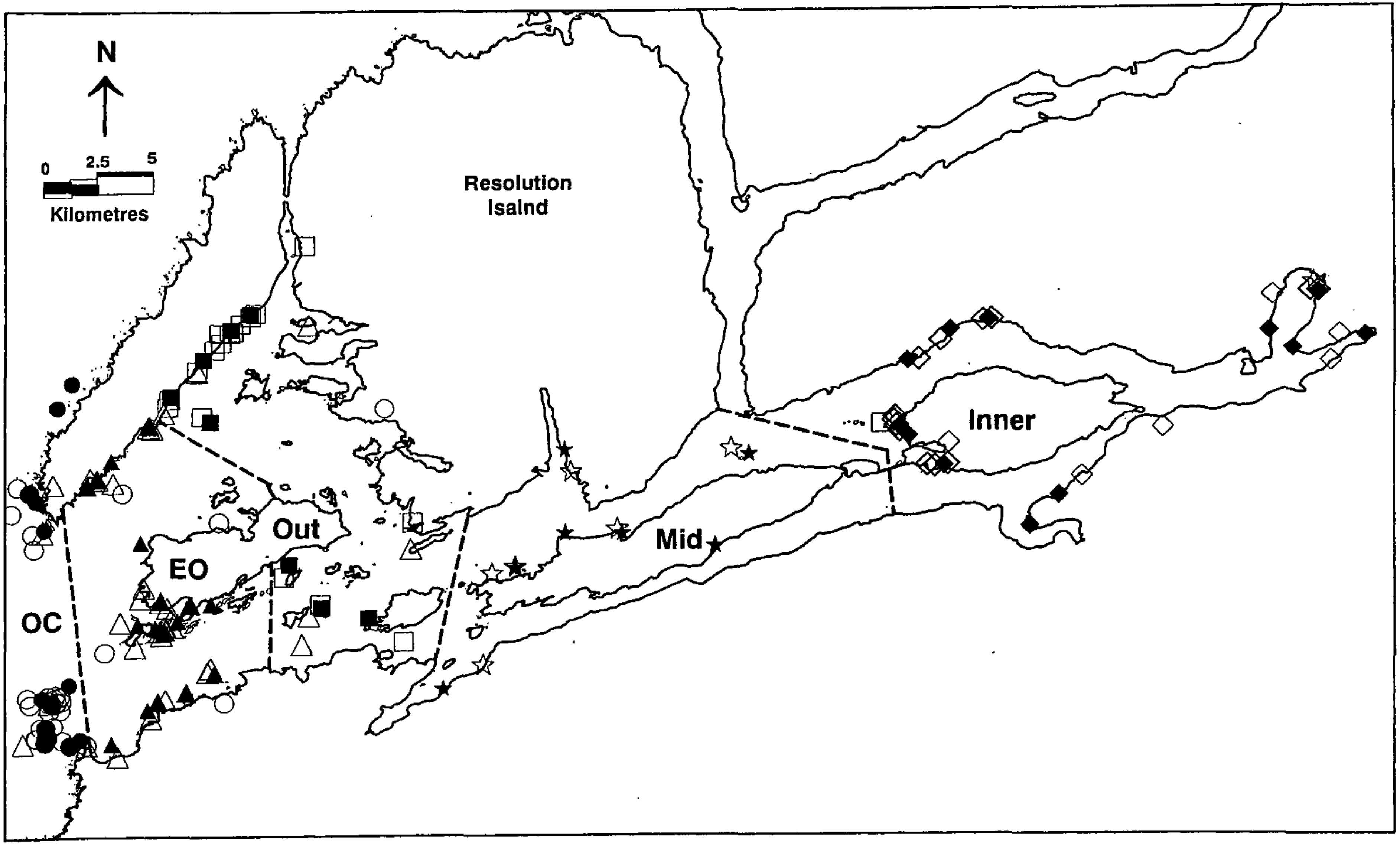


Figure 7: The location of release (solid symbols) and recovery (open symbols) sites of all tagged blue cod recaptured throughout five strata of Dusky Sound (n=147). OC – ● open coast, EO – ▲ extreme outer, Out – ■ outer, Mid –★ middle, Inner – ◆.

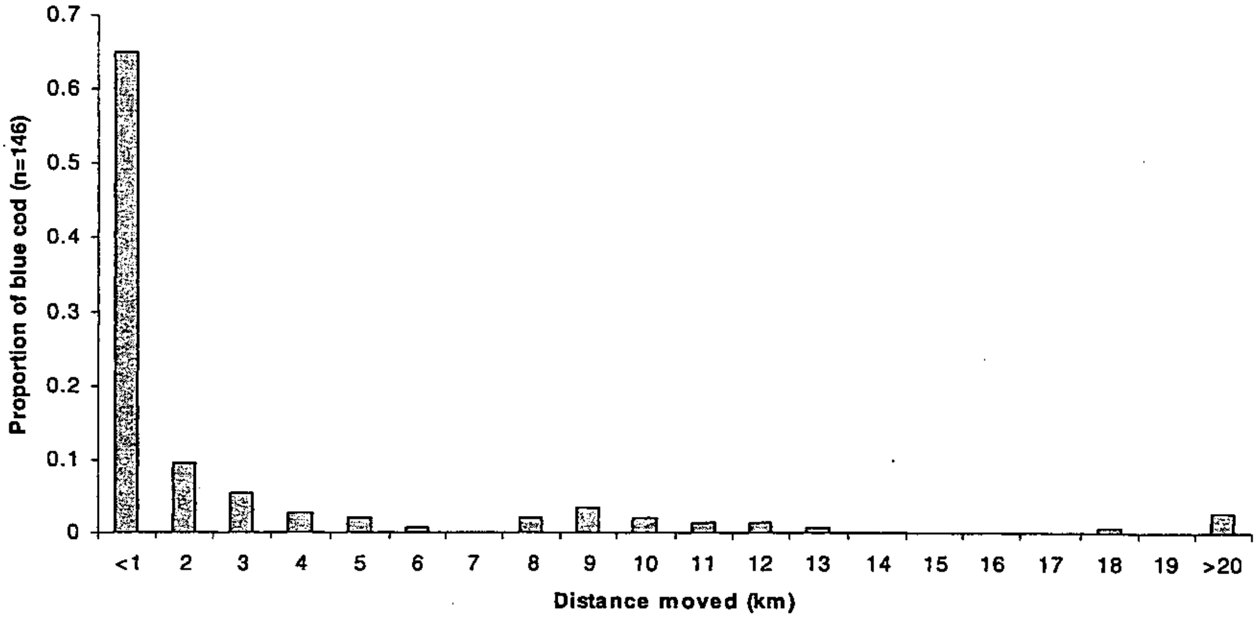


Figure 8: Distance moved by blue cod reported by the public and those caught in the recovery phased (n=147).

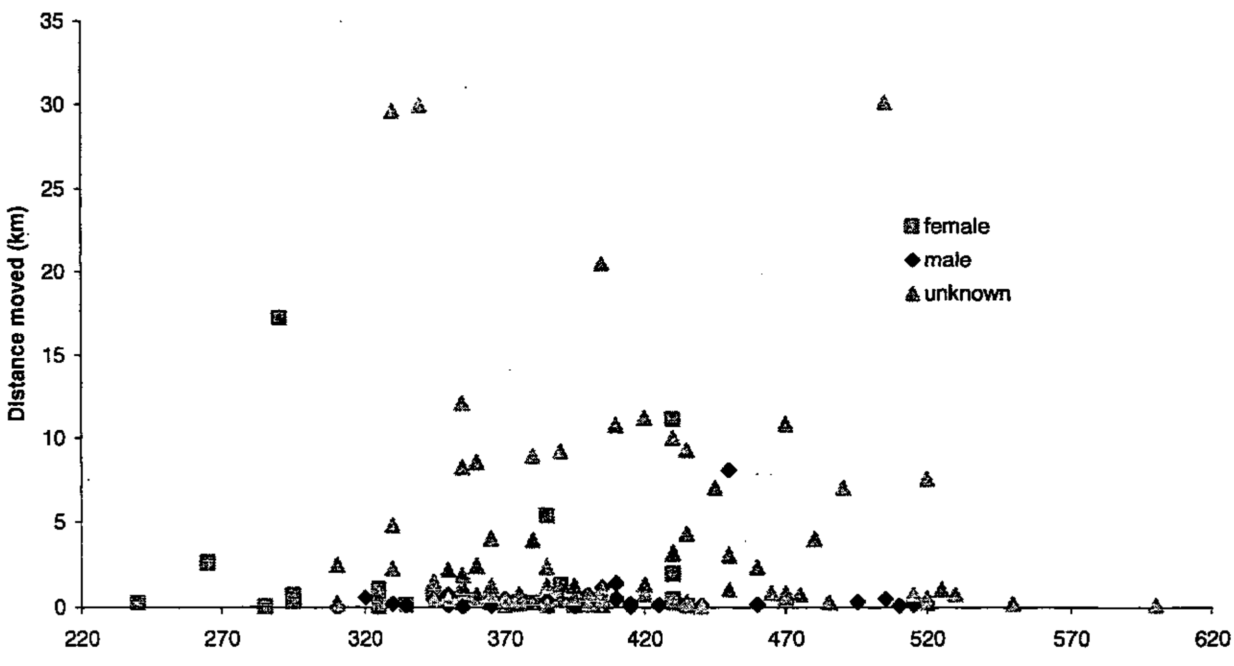


Figure 9. Distance moved by size (at tagging) blue cod reported by the public and those caught in the recovery phased (n=147).

Appendix 1: Dusky Sound stock mixing model

Dusky Sound is divided into four zones:

1. Outside open coast [OC]
2. Outer sound [O]
3. Mid sound [M]
4. Inner sound [I]

Fish were tagging in all four areas and fish were recovered from all four areas over the following year. Observations of tagged fish movement between zones are given in Table 1.

Table A1: Tag recoveries by zone of release and recapture

Tag recoveries
M2

		recovery zone			
		OC	**O**	**M**	**I**
	OC	12	0	0	0
	O	0	10	2	0
Release Zone	**M**	0	0	13	1
	I	0	0	0	25

Based on the observed movements of tagged fish between zones, the following movement hypotheses were developed:

1. There is no movement of fish between the open coast and Dusky sound.
2. There is no outward movement of fish across zones.

Movements between Dusky Sound zones are defined by the following probabilities

P[OO]	probability fish does not leave the outer zone
1-P[OO]	probability that a fish moves from the outer to inner zone
P[MM]	probability that a middle zone fish does not move
1- P[MM]	probability a middle zone fish moves to the inner zone

By the hypothesis

P[II] the probability that an inner zone fish stay put is =1

Peterson models for estimating the population size in each area after mixing has occurred are as follows:

$$N_{TOT}I = \frac{P[II]n_{1I} \cdot n_{2I}}{m_{2II}}$$

$$N_{TOT}I = \frac{(1-P[MM])n_{1M} \cdot n_{2I}}{m_{2MI}}$$

$$N_{TOT}M = \frac{P[MM]n_{1M} \cdot n_{2M}}{m_{2MM}}$$

$$N_{TOT}M = \frac{(1-P[OO])n_{1O} \cdot n_{2I}}{m_{2OM}}$$

$$N_{TOT}O = \frac{P[OO]n_{1O} \cdot n_{2O}}{m_{2OO}}$$

Solutions for the movement probabilities can be derived from known values as follows

P[II] = 1 by definition

P[MM] = $1-\frac{N_{TOT}I \cdot m_{2MI}}{n_{1M} \cdot n_{2I}}$ (from Equation 2)

P[OO] = $1-\frac{N_{TOT}M \cdot m_{2OM}}{n_{1O} \cdot n_{2M}}$ (from Equation 4)

Method for deriving 95% confidence intervals on population estimates and movement probabilities

Variation on the derived tagging estimates and movement probabilities was derived by bootstrap re-sampling (with replacement) from the observed pool of tag recoveries for each zone. A total of 1000 bootstraps was undertaken.