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EXECUTIVE SUMMARY

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A population survey of toheroa on Ninety Mile Beach, Northland, was undertaken during May 2006. The area was initially stratified through examination of the beach for dense siphon holes (denoting toheroa beds) and limited exploratory digging every 1 km in March 2006. The beach was divided into six strata, representing different (putative) toheroa densities and/or areas along the beach. A two-phase, stratified random survey was undertaken using transects orientated down the beach slope, with 0.25 m^2 quadrats dug at 10 m intervals down each transect.

The overall population of toheroa was 8.88 million (c.v. 31%), with only one animal over 75 mm being sampled, and none over 100 mm. Most of the population was composed of juveniles less than 50 mm in length. No well defined beds were identified. Some problems were encountered with the stratification method. A tuatua abundance estimate was also obtained for a subarea of the beach (47 km, spread across several strata), with an intertidal population estimate of 486 million individuals (c.v. 42%), with most of these animals being 30–60 mm in length.

As of May 2006, toheroa population/s on Ninety Mile Beach have not recovered to their historically high abundance levels, with the age structure dominated by juveniles and sub-adults, with very few larger adults on the beach. The relatively infrequent population surveys on the beach (three since 1986, including this current survey) combined with a lack of process-focused work, mean that our understanding of the factors limiting population sizes will remain poor into the foreseeable future.

1. INTRODUCTION

1.1 Overview

Toheroa are large infaunal surf clams which historically supported regionally important cultural, recreational, and commercial fisheries. Once abundant on exposed surf beaches in Northland, Wellington, and Southland, populations have declined to levels where harvests are no longer permitted. The reasons for these declines are poorly understood, but are likely to include a combination of over-harvesting, environmental changes, and other impacts such as heavy vehicle traffic along some beaches.

Monitoring of the main northern North Island populations (Ninety Mile, Dargaville, and Muriwai Beaches – Figure 1) has been carried out sporadically for more than 70 years. Gathering has not been permitted from these beaches since 1971, 1980, and 1976 respectively, but monitoring of the stocks has continued, with surveys being undertaken annually up until 1986. Since 1986, only brief inspections have been carried out in 1990 and in 1993. In 1999 a full survey was completed for Dargaville Beach (Akroyd et al. 2002) and in 2000 for Ninety Mile Beach (Morrison & Parkinson 2001). This report summarises the results of the most recent toheroa survey in Northland, undertaken on Ninety Mile Beach in May 2006. A two phase, stratified survey was used to estimate the population size and abundance of the toheroa population on the beach, down to the low water mark. Concurrent estimates of tuatua abundance were made opportunistically for a subset of these strata.

This project was funded through MFish contract TOH2005/01. The specific objective was as follows: "To determine the distribution of toheroa beds, and the abundance and size structure of toheroa, for specific areas of Ninety Mile Beach on the west coast of the North Island. The target coefficient of variation for the estimates of absolute abundance is 20%".

1.2 Description of the fishery

Commercial harvesting of toheroa ceased in northern New Zealand in 1969 as a result of populations declining to very low levels. Recreational harvesting ceased for Ninety Mile Beach in 1971, for Muriwai in 1976, and for Dargaville in 1980 (Stace 1991). Populations have not recovered since that time, and no harvesting (apart from customary purposes) has been permitted since the closures.

1.3 Literature review

Toheroa are a distinctive element of the fauna of exposed surf beaches in several parts of New Zealand. Beaches that have historically supported abundant populations include Ninety Mile, Dargaville, and Muriwai Beaches on the west coast, Northland; Foxton, Waitarere, Hokio, Otaki, and Waikanae along the Wellington coast; and Te Waewae and Oreti Beaches in the far south (Redfearn 1974). Less important beach populations have been recorded from Mitimiti, Whangape, Piha, and Pollok (west coast North Island); Spirits Bay and Tom Bowling Bay (top of North Island); Tokerau and Te Arai (east coast North Island); Opotiki and Ohope Beaches (Bay of Plenty); Hampden, Waikouaiti, and Long Beaches (bottom of South Island) (Redfearn 1974). All of these populations are intertidal. Suggestions have been made that subtidal populations may also exist, based on "missing" cohorts (Cassie 1955) and evidence of drilling of toheroa shells by gastropod species that are absent from the intertidal (Waugh & Greenway 1967), but no direct evidence exists.

Adult sex ratios are equal, with most animals maturing in their second year (Redfearn 1974). Various proportions of the adult population are ripe for spawning throughout the year, but higher proportions are associated with rising sea temperatures. Partial spawning occurs from October to March, although minor spawning periods have also been observed in May–June. Rapson (1952) suggested a planktonic larval duration of 10–12 days. Intervals of at least a month have been noted between spawning events and the presence of spat on Dargaville Beach (Redfearn 1974).

Recruits 2 mm in size have been observed being carried up the beach on wave fronts. Redfearn (1974) reported that these settled into the sand in the slack water interval before each wave receded, and buried themselves to a depth of 1–2 cm. Settlement on the beach was determined by the fetch of the wave. After several weeks a band of juveniles formed just below high water mark. Historically, these juvenile beds sometimes extended for many kilometres (Redfearn 1974). Highest density settlement was recorded in the small bays formed along the beach, which were also where adult beds often occurred. Rip currents adjacent to these bays may aggregate larvae in an analogous manner to floating debris (Redfearn 1974). A gradual movement of animals down the beach subsequently occurred.

Historically, adult toheroa beds ranged from discrete populations 55–110 m long, separated by kilometres of empty beach (Muriwai), through to continuous beds stretching for kilometres (Dargaville) (Greenway 1969). Size trends along beaches have sometimes been noted (increasing size going north), suggesting movement along the beach. Anecdotal observations suggest passive migrations of thousands of animals along the beach can occur over short time scales (Redfearn 1974). Movements up and down the shore may also occur, with beds moving 30 m or more during a night (Redfearn 1974). Greenway (1969) noted that although tagging experiments found most recoveries close to release points, some individuals were recovered several miles away. However, Rapson (1954) discussed occurrences of misshapen shells and reductions in growth rates in dense beds, suggesting that some beds at least are very stable in their location.

Toheroa are filter feeders, with Cassie (1955) noting that a feature common to all beaches with abundant toheroa populations was the frequent occurrence of dense concentrations of algae (especially diatoms) that often formed "thick, greenish scum on the water's surface", extending for 110 m or more out to sea. High proportional abundance of such food may be important to effective feeding, as toheroa are unable to actively select organic material from the water column and may experience problems under conditions where most ingested items are inorganic (Cassie 1955).

Toheroa lay down shell rings, which have been used for ageing animals assuming these rings are annual (an assumption that does not appear to have been validated). Assuming annual rings, North Island toheroa take 4–5 years to reach 'legal' size (100 mm) (Cassie 1955), while Southland animals are slower growing, taking 7 years (B. Street, unpubl. data, in McKinnon & Olsen 1984). Ages of 15 years were stated to be "not uncommon" on Muriwai beach by Cassie (1955), and Brunton (1978) mentioned 23 year old toheroa as being not uncommon in the South Island.

An unusual feature of northern beaches is the presence of very large dead toheroa shells which are heavier and bulkier than the shells of live animals found in the same area. These large shells may be sub-fossils, representing a species (or sub-species) of toheroa now extinct. (Cassie 1955). Shell ring counts from these shells have produced ages of up to 18 years. There has been speculation that these large animals may persist in sublittoral populations, but no direct evidence exists. An anecdotal report from the late 1940s from a local inspector of fisheries at Himatangi (Wellington coast) mentions large toheroa nearly one foot (305 mm) long (referred to as 'bottlers') being "littered" along the beach after an especially severe storm.

2. REVIEW OF THE FISHERY

2.1 Commercial harvesting

Commercial harvesting began in the late 1800s, with the first cannery opening at Dargaville in 1904; two were in operation by 1911. By 1923, only one of these was still in operation, but a second opened on Ninety Mile Beach. By 1945 this cannery had shut down, although it re-opened briefly from 1962 to 1964. Overall commercial production of toheroa peaked in 1940 at 77 t, but then rarely exceeded about 20 t (Redfearn 1974). Quotas were introduced in 1962, based on annual population surveys. The Dargaville cannery continued seasonal operations in most years until 1969 (Redfearn 1974). However, by 1969 substantial declines in abundance led to the termination of commercial harvesting. Despite this, population numbers continued to decline, and recreational harvests ceased for Ninety Mile Beach in 1971, for Muriwai in 1976, and for Dargaville in 1980 (Stace 1990). Adult populations have not recovered since then.

2.2 Other information

There is no other information on harvests or fisheries relevant to this study. However, large fluctuations in abundance appear to be a natural component of the population dynamics of toheroa. Poaching is also likely to be of some importance.

2.3 Recreational and Maori customary fisheries

Currently there is no allowable recreational harvest for toheroa in New Zealand. Levels of customary take are unknown.

2.4 Other sources of mortality

Gulls (black-backed, *Larus dominicanus*, and red-billed, *L. novaehollandiae*) are important predators of toheroa (Brunton 1978). Small toheroa are eaten whole, while larger toheroa are carried into the air and then dropped two to three times until they crack. Animals up to 120–130 mm long can be handled. Rates of consumption of 20 toheroa per day (4–6 cm) were noted: thus a gull population of 353 individuals could consume 1.5 million toheroa in a year (Brunton 1978). Predation by fish, snapper in particular, may also be important, with toheroa siphon nipping being common (Redfearn 1974).

Mass mortalities appear to be a regular feature of toheroa populations, especially during summer. In 1930, an 8–10 mile (*ca.* 13–16 km) stretch of Ninety Mile Beach suffered heavy toheroa mortality due to dry sand being blown from the sandhills on to the beach by strong continuous easterly winds, with "toheroas presumably being suffocated" (Anon 1931, Rapson 1954). High summer mortality reported on all the Northland beaches in 1938 (Rapson 1954) was considered to be a result of lack of oxygen, and heat stress, resulting from calm surf conditions and tides not covering the toheroa for several days. Animals were also in poor condition from spawning. Heavy mortalities were also noted for the three main northern beaches during the summer of 1970–71 (Greenway 1972). Strong inshore winds with an associated sharp drop in air temperature have also been suggested as the cause of toheroa mortalities at Te Waewae Bay, Southland (Eggleston & Hickman 1971).

At Bluecliffs Beach in the South Island, population declines have been attributed to changes in beach profile and sediment type (Cranfield (1996), cited by Carbines & Breen 1999), with scouring events removing the finer sediment components of the beach leaving a layer of coarse sand that may be unsuitable for toheroa burrowing (McKinnon & Olsen 1994, Carbines & Breen 1999).

The passage of vehicles along the beach is also considered to be a significant mortality agent. Hooker & Redfearn (1998) found mortalities (crushed shells) of up to 14% in small toheroa (range 6–23 mm, mean 10–12 mm) following heavy vehicle use of the beach for a large recreational fishing contest.

The illegal fishery for toheroa may also be very significant. Estimates of illegal take are not available.

3. RESEARCH

3.1 Stock structure

Little is known about the stock structure of New Zealand toheroa. The three northern North Island beaches that historically supported abundant populations (Ninety Mile, Dargaville, Muriwai) may be connected via planktonic dispersal of larvae, but lack of information on local current speeds and direction makes this a tentative suggestion only.

3.2 Resource surveys

There is a long history of stock surveys for toheroa on northern beaches, starting at the beginning of the 20th century. As far back as 1926, concerns were being raised about the over-harvesting of the resource (Anon. 1926).

From 1962 to 1969 biennial surveys were conducted on the three main beaches. These surveys usually consisted of a narrow trench (0.5 m) being dug down the beach about every 900 m, and all toheroa being excavated and measured. From this, densities were scaled up to the level of the beach. These were designed as before season / after season surveys, in order to manage the stock, but by 1967 the population was at such a low abundance that all harvesting ceased (Greenway 1969, 1972). Greenway noted that the accuracy of these surveys was modest, and not sufficient to be able to make estimates of the amount removed from the stock during the open seasons.

After harvesting ceased, annual population surveys continued through the seventies and early eighties until 1986. Subsequently, brief investigations were carried out in 1990 (data not available) and in 1993 (1 day each at Ninety Mile and Dargaville Beaches). In 1999 a full survey was carried out of Dargaville Beach (Akroyd et al. 2002), while Ninety Mile Beach was surveyed in 2000 (Morrison & Parkinson 2001). The survey reported in this document represents the latest toheroa survey (Ninety Mile Beach, May 2006).

Abundance estimates for toheroa from the early 1930s up to the present, for the three main northern beaches are shown in Figure 2. A distinction is made between animals greater and less than 75 mm, which is a historical minimum size limit. Associated size frequencies are given in Figure 3. In general, the abundance of toheroa declined over the survey period for all beaches.

In the early 1960s, a good proportion of the stock was composed of animals over 75 mm (about 3 inches), for Ninety Mile and Dargaville Beaches. A substantial decline was apparent in adult animals up until 1971 for Ninety Mile Beach, and 1974–77 for Dargaville, when numbers rose briefly again, before declining to relatively very low levels. Over this period Muriwai Beach had consistently low adult abundances, although numbers appeared to have been higher historically (1935–53). The two more northern beaches (Ninety Mile in particular) had three years of extremely high juvenile recruitment (arbitrarily defined as animals of less than 75 mm – probably representing 0+/1+ animals). These peaks occurred on Ninety Mile Beach in 1964 and 1971 and on Dargaville Beach in 1972. Smaller peaks also occurred on Dargaville and Muriwai Beaches during the time series. These recruitment events did not result in large adult population abundances 2 to 3 years later, suggesting that large scale mortality was eliminating these recruitment pulses from the population before adult size was reached.

Given the once abundant larger size classes on these beaches, which supported commercial canning operations, it appears that some aspect of the population dynamics, or supporting habitat, has changed so that these areas can no longer support large adult beds of toheroa. Over the last 40 years, populations appear to have received erratic (if occasionally quite substantial) recruitment pulses, followed by large scale mortality that prevents increases in adult abundance. The Dargaville Beach 1999 and Ninety Mile Beach 2000 surveys reported substantial numbers of small toheroa, suggesting recent large scale recruitment.

3.3 Other studies

Beentjes *et al.* (2006) formally reviewed and synthesised data from a series of 42 toheroa surveys of Blueliffs Beach, Southland, covering the period 1966 to 2005. They found that overall toheroa abundance declined from over 2 million adults in the mid 1960s to *ca.* 80 000 by 1990, and has since remained at low, but stable, numbers. Recent recruitment has been highly variable, but overall low, when contrasted with 1960s levels. Unlike upper North Island populations, the population size structure at Bluecliffs Beach has consistently shown both adult and juvenile size class modes, with few in the intermediate size classes range.

3.4 Estimates of population size and size structure in 2006

3.4.1 Survey methods

To estimate total population size and associated size frequency distributions of toheroa on Ninety Mile Beach, a two-phase stratified random survey was undertaken in May 2006. A preliminary examination of the beach was undertaken in March 2006. The beach was traversed in a vehicle driven at low speed, with a driver and an observer looking for signs of toheroa beds. These were evident as areas of double siphon holes in the sand, with a 'pocked' aspect to the sand surface. In addition, at 1 km intervals a series of small excavations was made down the full extent of the beach slope, looking for toheroa. A differential GPS was used for spatial positioning (± 10 m accuracy) along the beach. Notes were kept of the relative density of animals (measured qualitatively by eye) and their dominant size range. Combining these two observations (siphon hole areas and density 'bins'), the beach was divided into six strata (Table 1).

Phase 1 transects were allocated across the strata in numbers thought to be roughly representative of the area of the stratum and its likely toheroa density. Phase 2 transects were allocated on the basis of maximising reductions in the variance estimates. This was achieved by adding a transect iteratively to each stratum, and using the existing density and variance information to predict the likely improvement in the c.v. for each possible stratum allocation. The transect was then assigned to the stratum giving the greatest improvement in the overall c.v., and the process repeated until all available phase 2 transects had been allocated (*sensu* Francis 1984).

Each transect was assigned a random starting point 0–9 m below high tide mark. Transect positions along the beach were located using differential GPS. Quadrats were dug at 10 m intervals down the transect to the lowest point on the beach possible given the tide.

Quadrats were positioned using a rope knotted at 10 m intervals, minimising potential wind and passing vehicle problems (relative to using tape measures). At each 10 m interval, a 0.5 x 0.5 m (0.25 m^2) steel quadrat with vertical sides was driven into the substrate, and excavated to a depth of 30 cm. To allow for potential edge effects, animals encountered on the seaward edge of the quadrat or the left edge of the quadrat facing up the beach were included in the sample; any animals encountered on the landward edge or the right edge facing up the beach were excluded. All of the sand excavated was placed on small trolleys supporting an aluminum box with a floor composed of a 5 mm screen. These trolleys were wheeled down to the water, and placed in the water so that the sand was washed through the sieve, leaving behind any shellfish present. The maximum dimension of individual animals was measured to the nearest whole millimetre down.

The basic sampling unit for analysis was the mean quadrat density for each transect rather than that for each quadrat. Since a stratified random approach was used, the following equations were applied.

The sample mean for stratum *h* was calculated as

$$\overline{y_h} = \left[\sum_{i=1}^{n_h} y_{hi} \right] / n_h$$

where

h	denotes the stratum being considered
i	denotes the sampling unit (average density per quadrat, within a transect)
y_{hi}	denotes the value of the ith unit of stratum h
n	is the sample size taken (number of transects sampled)

The sample variance for stratum *h* was calculated as

$$s_h^2 = \left[\sum_{i=1}^{n_h} (y_{hi} - \overline{y_h})^2) \right] / (n_h - 1)$$

As random sampling was done in each stratum, the sample mean is an unbiased estimate of the population mean, and the sample variance is an unbiased estimate of the population variance. To combine all of the sampling strata on a beach to get a beach population mean and variance, the stratified estimator was

$$\overline{y_{st}} = \sum_{h=1}^{L} W_h \overline{y_h}$$

where W is the weighting given to each stratum contribution (in this case the area of each stratum within the beach) and L is the number of strata.

The variance estimator was

$$\mathrm{var}(\overline{y_{st}}) = \sum_{h=1}^{L} W_h^2 \frac{s_h^2}{n_h} \left(\frac{N_h - n_h}{N_h} \right)$$

where N_h is the population size in stratum *h*.

The coefficient of variation for the overall population of a shellfish population at a beach was simply

$$\mathrm{c.v.} = \frac{\sqrt{\mathrm{var}(\overline{y_{st}})}}{\overline{y_{st}}} \mathrm{x} 100$$

3.4.2 Survey results and discussion

Toheroa were uncommon on the beach, with only 124 individuals being sampled. Most of these were juveniles, and only one individual longer than 75 mm was encountered. No identifiable beds were encountered, and the distribution of toheroa could best be described as very variable and patchy (Figure 4). An estimated 8.8 million toheroa (c.v. 31%) were present. Limited additional searching of specific areas of the beach, specifically identified by local iwi as being good gathering spots, failed to find any further concentrations of toheroa.

The bulk of the population was composed of animals of 50 mm or less (*see* Figure 3), which were probably a 0+ cohort (Redfearn 1974). There was evidence of two peaks in the size frequency data (see Figure 4), suggesting either multiple successful spawning events or the presence of two age classes. Fewer animals were found in the 50–74 mm range, and only one individual exceeded 75 mm in length.

Some issues were encountered with the survey stratification. This was largely due to tuatua being found in very high abundances at much higher tidal heights than considered 'normal', resulting in some unexpected misidentification problems between juvenile toheroa and juvenile tuatua in the initial stratification survey. While this issue was rectified in the main survey through careful use of identification guides and diagnostics, it meant that the initial stratification of the beach was not optimal. Given the very low abundances of toheroa on the beach, the effects of this suboptimal stratification were quite unlikely to have significantly affected the final conclusions, but probably resulted in some inflation of the c.v. Aside from the (resolved) misidentification issue, future surveys should evaluate alternative stratification approaches, as surface siphon sign appears to vary depending on environmental and/or other variables, while digging of exploratory holes along the beach is limited by logistic constraints. Suggestions have been made that elevated toheroa abundances are often associated with areas of higher freshwater seepage onto the beach. If this is correct, then undertaking surveys in winter (when water run-off is more obvious) might allow such habitat relationships to be exploited to better stratify the beach.

Tuatua abundance and population size structure were also estimated from data collected on the last day of the survey, for 47 km of beach. Within this area, a population of 486 million (c.v. 42%) tuatua were present, consisting mainly of animals 30–60 mm in length (Figure 5).

3.5 Growth

As part of the current project, attempts were made to generate length-at-age growth curves from the historical time series using the software Multifan. Despite the presence of apparent age classes which increased in average size through time (see Figure 3), no sensible fits were able to be generated from the historical length-frequency data series.

Using a mark-recapture method at Bluecliffs Beach, Southland, Beentjes & Gilbert (2006) found toheroa to grow rapidly from small juvenile sizes, reaching an adult size at about three years of age. Beyond this, a strong adult mode of 110–145 mm was thought to represent the accumulation of many year classes (3–20 years), with substantially slower growth at these larger sizes, along with relatively low mortality (Beentjes & Gilbert 2006).

For northern populations, direct estimation of growth through tagging would be useful in any future research programme, using metal tags able to be remotely detected, as done for cockles by Stewart & Creese (2000).

3.6 Yield estimates

No yield estimates are available for toheroa.

4. MANAGEMENT IMPLICATIONS

The abundance of toheroa in May 2006 was modest in terms of the longer survey time series available. The population was dominated by small toheroa under 50 mm in length (0+/1+ cohort). It should be noted that this survey may have been more efficient at sampling smaller toheroa (about 30 mm) than previous surveys which did not use sieves (pre 2000 survey). The size frequency from 2006 was similar to that recorded in 2000. Many small juveniles were also found on Dargaville Beach in 1999 (see Figure 3) (Akroyd et al. 2002).

In the present survey, no discrete beds were found along Ninety Mile Beach, and only one toheroa longer than 74 mm was encountered. Historically, the abundance of these larger animals has ranged up to 5–10 million (mid 1960s, 1970–71) during the survey period (and probably higher before this), although for most of the time series, abundance has been very low.

The historical time series shows that large recruitment events occur at irregular intervals, but these fail to generate higher abundances of larger animals. This suggests that two general processes are acting to limit the 'regeneration' of large adult toheroa beds on the beach. The first is that recruitment is erratic, varying by at least two orders of magnitude over a scale of years, with many years having little or no recruitment. This pattern may be driven by large-scale climatic processes, but remains to be investigated. The second general process is that when large numbers of juvenile toheroa do recruit onto the beach, they suffer high mortality rates, the end result being few animals growing into adults. The specific processes operating can only be speculated upon, but may include poaching, impacts of vehicle traffic, changes in food availability, or changes in the physical habitat itself (such as lower freshwater run-off or changes in run-off chemistry due to pine forest plantations behind the beach system). These possibilities are not listed in any particular order, and none of them may necessarily be a contributing factor.

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Table 1: Stratum descriptions, areas, transect allocations, and transect densities.

Stratum*	Area (m^2)	No. of transects	
		Phase 1	Phase 2
None 1	2 746 800	4	11
None 2	2 585 000	4	–
Very low	892 500	3	1
Medium	485 900	5	1
High 1	467 500	4	2
High 2	1 650 000	5	2
	Total	25	17

*These descriptions were given at the time of the initial work to stratify the beach: subsequently it turned out that some strata thought to hold toheroa were in fact misidentifications of small tuatua.

Table 2: Estimated population size by stratum; coefficients of variation (c.v.) are given in parentheses.

Stratum	Species			
	Toheroa		Tuatua	
None 1	7 644 343	(35)	203 374 180	(92)
None 2	574 444	(100)		N/A
Very low	396 666	(100)		N/A
Medium	40 492	(100)		N/A
High 1	225 092	(59)	56 557 480	(92)
High 2		0	225 309 000	(27)
All strata	8 881 038	(31)	486 221 664	(42)

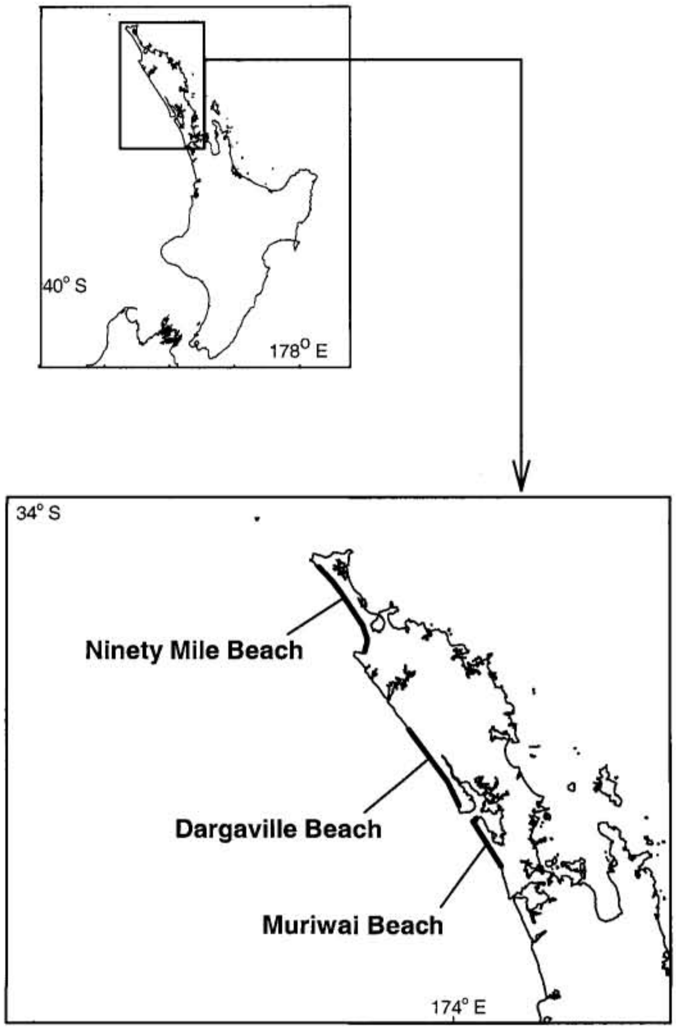

Figure 1: **Location of three main northern beaches that contain important toheroa populations**

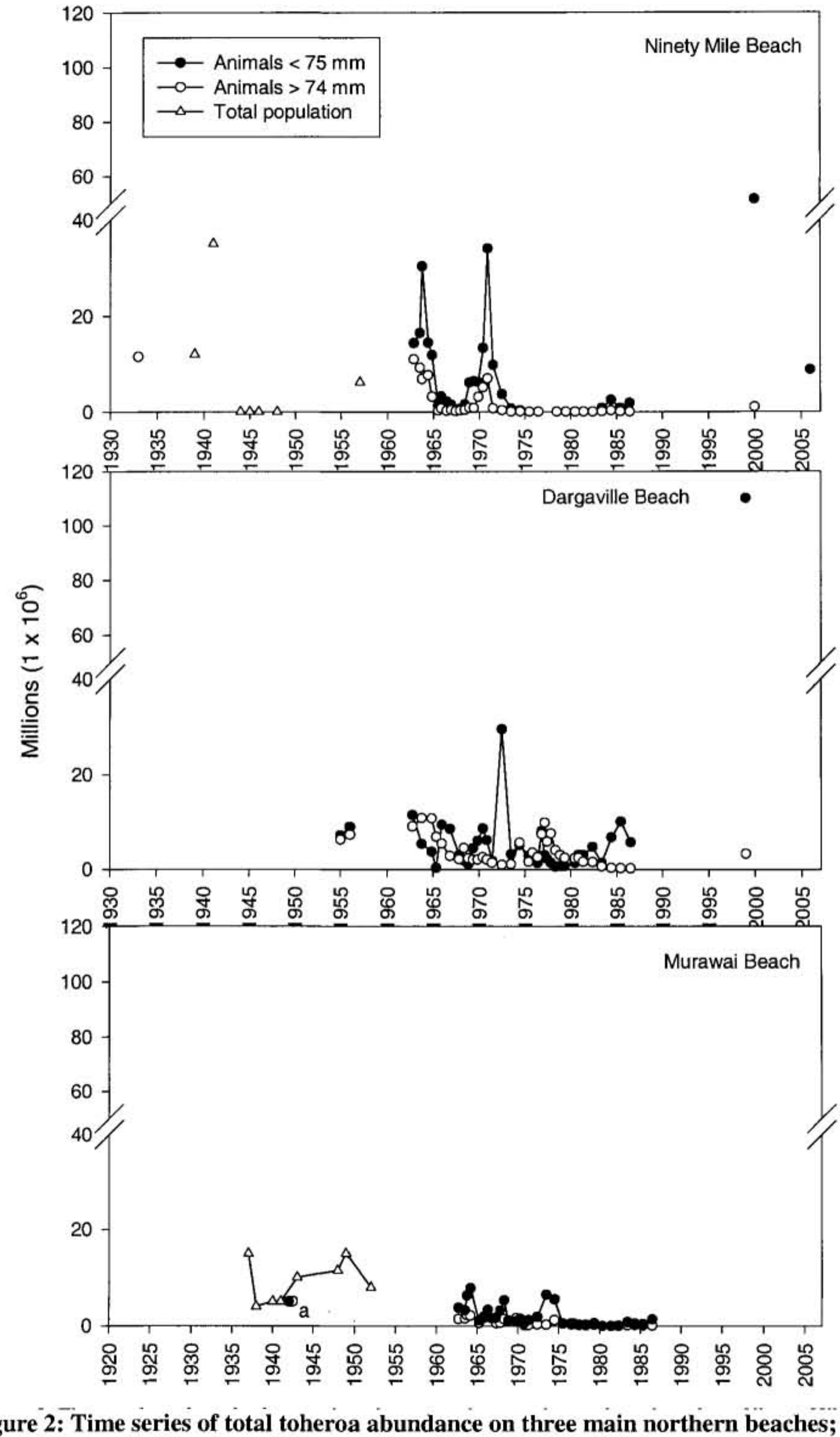

Figure 2: Time series of total toheroa abundance on three main northern beaches; Ninety Mile Beach, Dargaville Beach, and Murawai Beach, 1993–2006. "a" denotes a 1942 survey on Murawai Beach where the estimates of under and over 75 mm toheroa are slightly offset to allow both estimates to be viewed. Where total population estimates are given, no data are available that allow size divisions to be made.

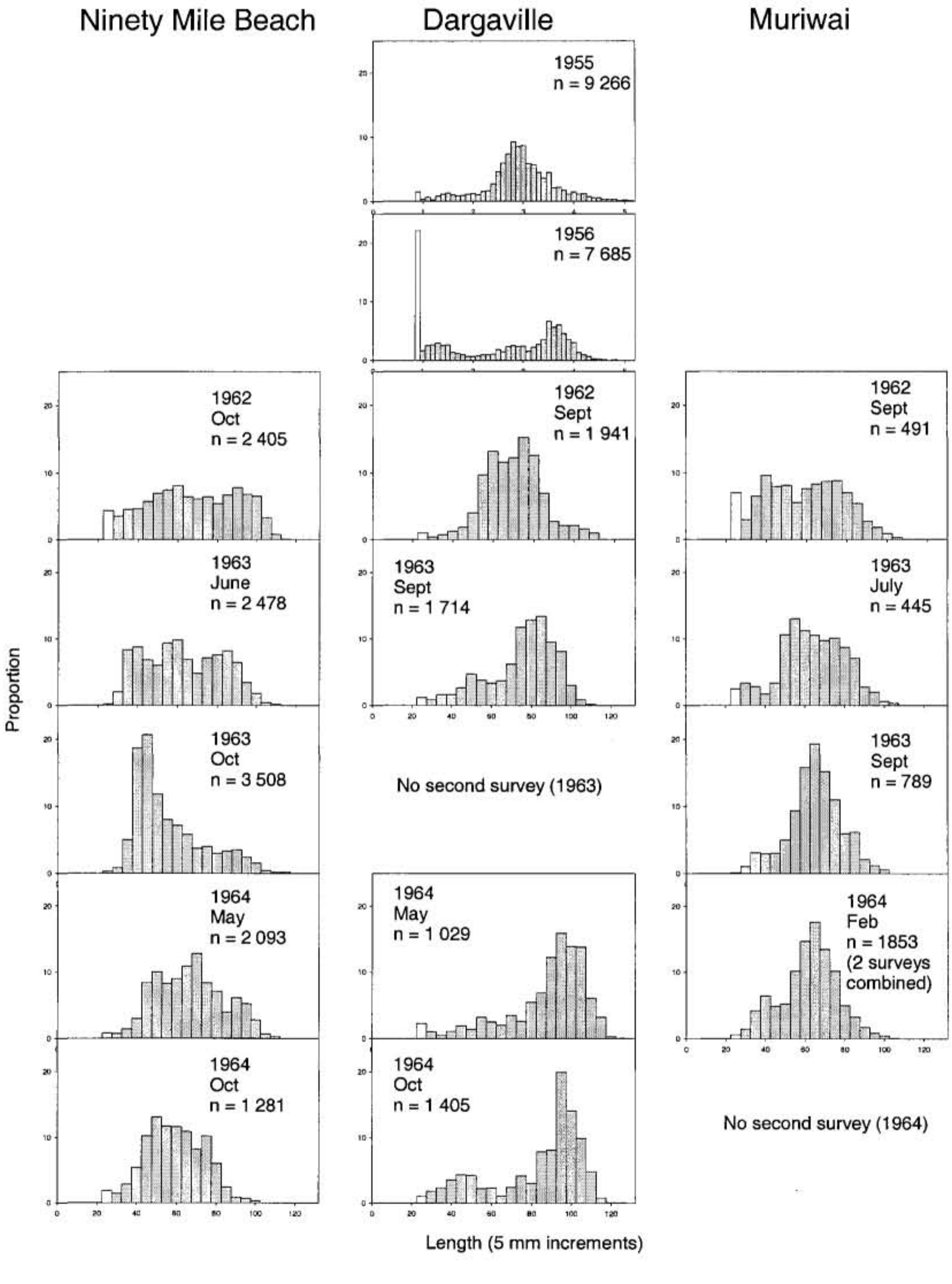

Figure 3: Length frequency time series for toheroa on three main northern beaches; Ninety Mile Beach, Dargaville Beach, and Murawai Beach, 1955–1964. 1955 and 1956 data are expressed in inches, data from 1962 onwards in mm. Animals < 30 mm (or less than 1 inch) are grouped into one white bar (historically recorded in this way), all other bars (grey) are for the size classes indicated.

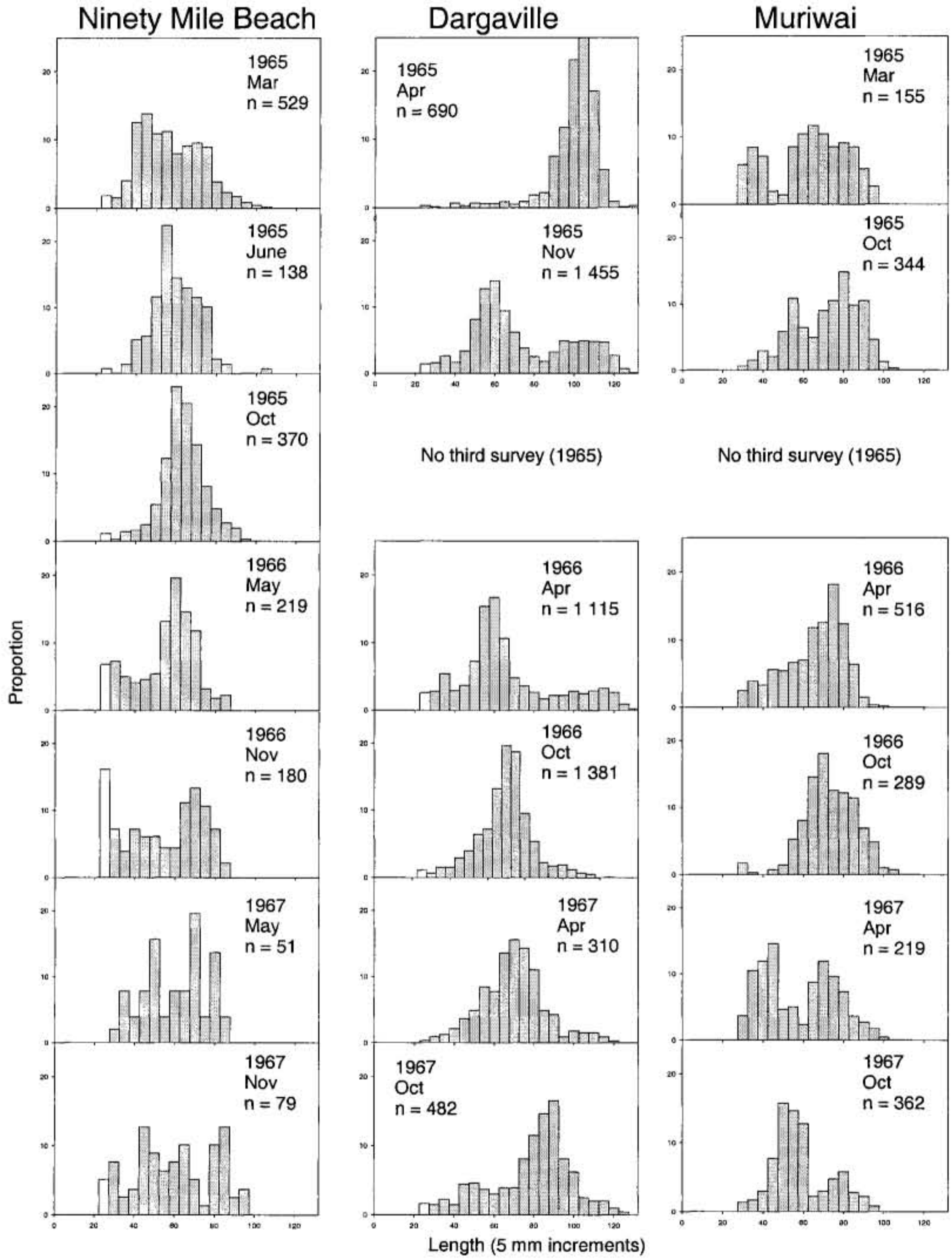

Figure 3: continued; 1965–67.

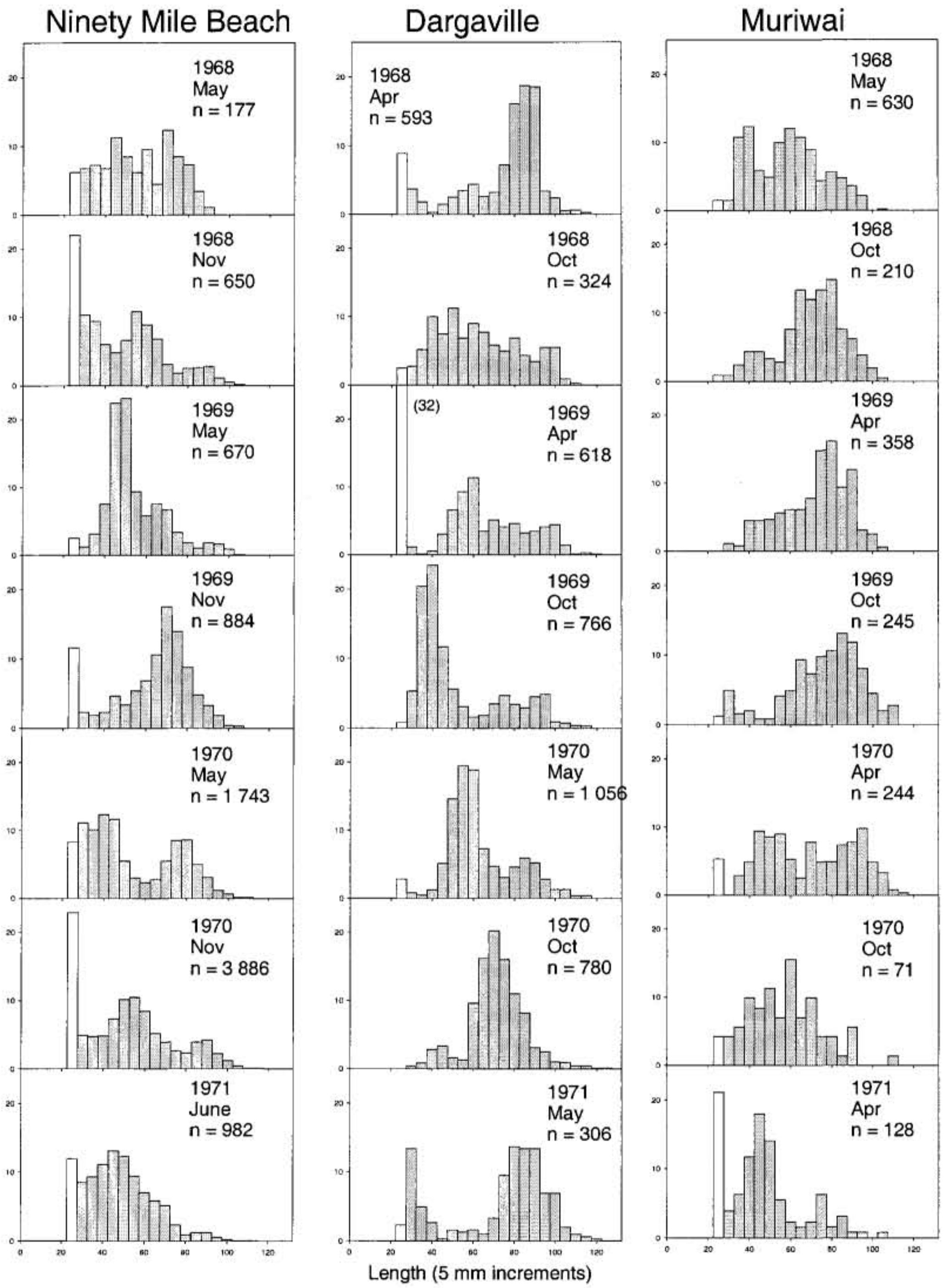

Figure 3 continued; 1968–71.

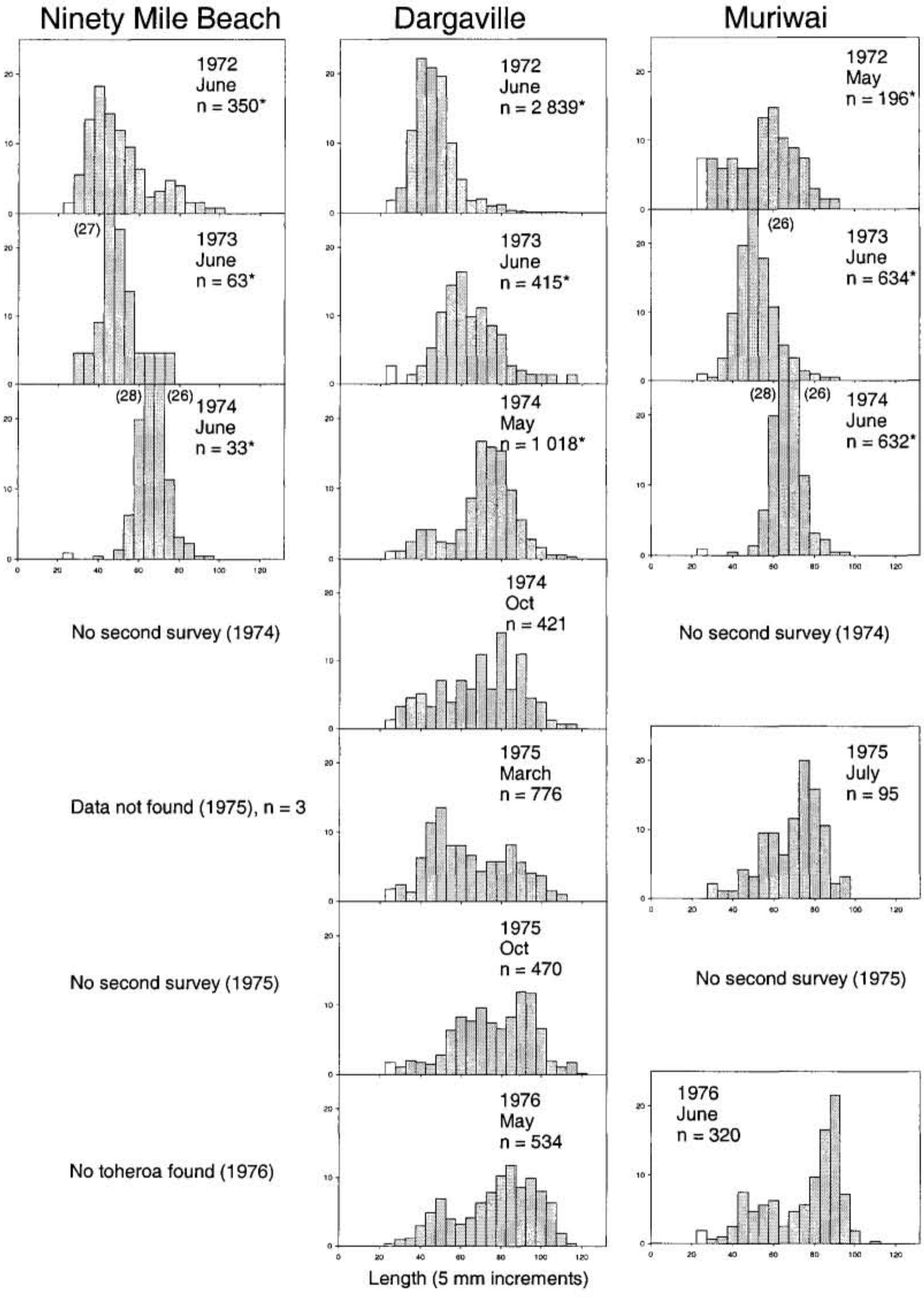

Figure 3 continued; 1972–76. Samples marked with "*" were derived from graphed data, the original numbers not being found.

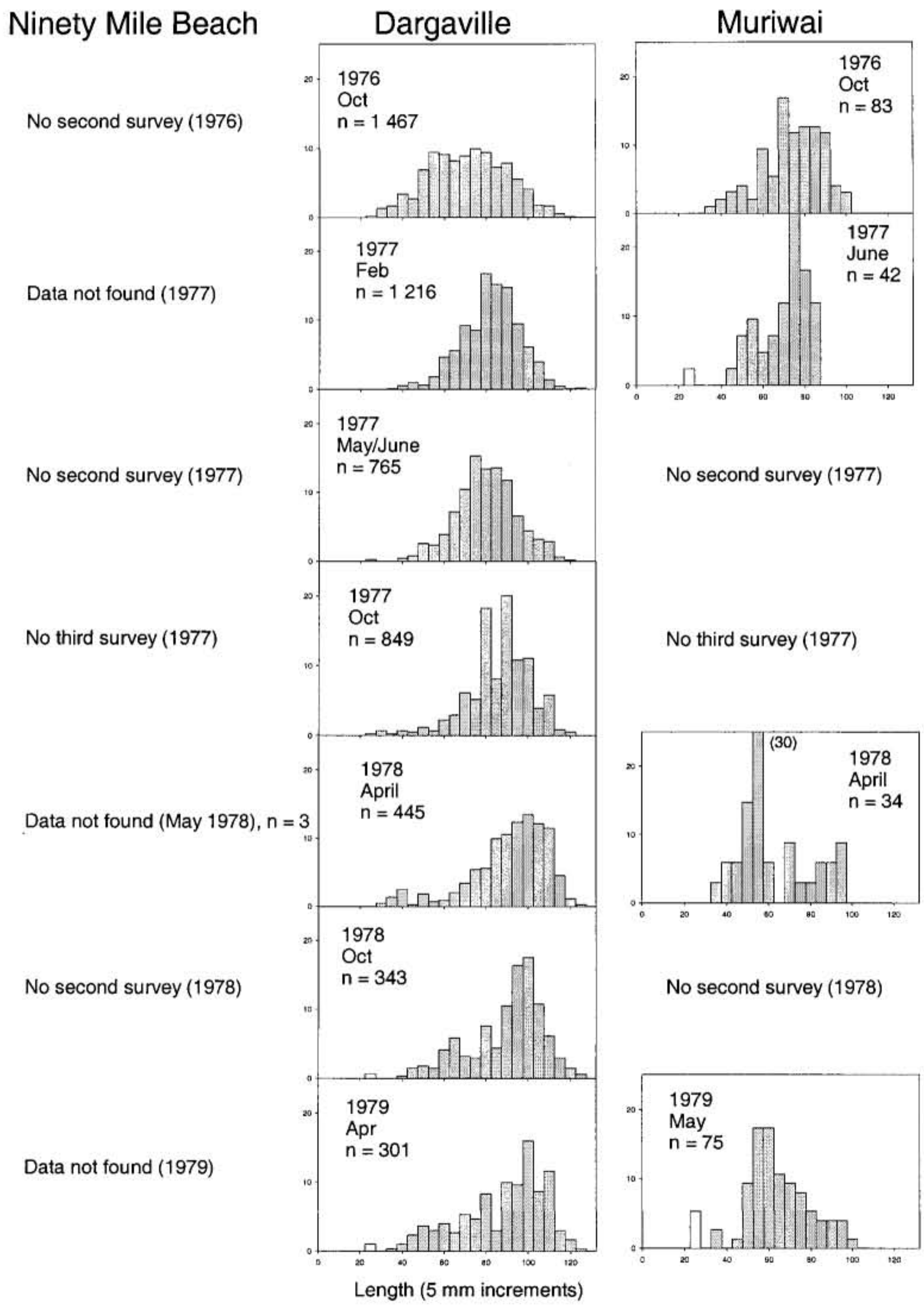

Figure 3 continued: 1976–79.

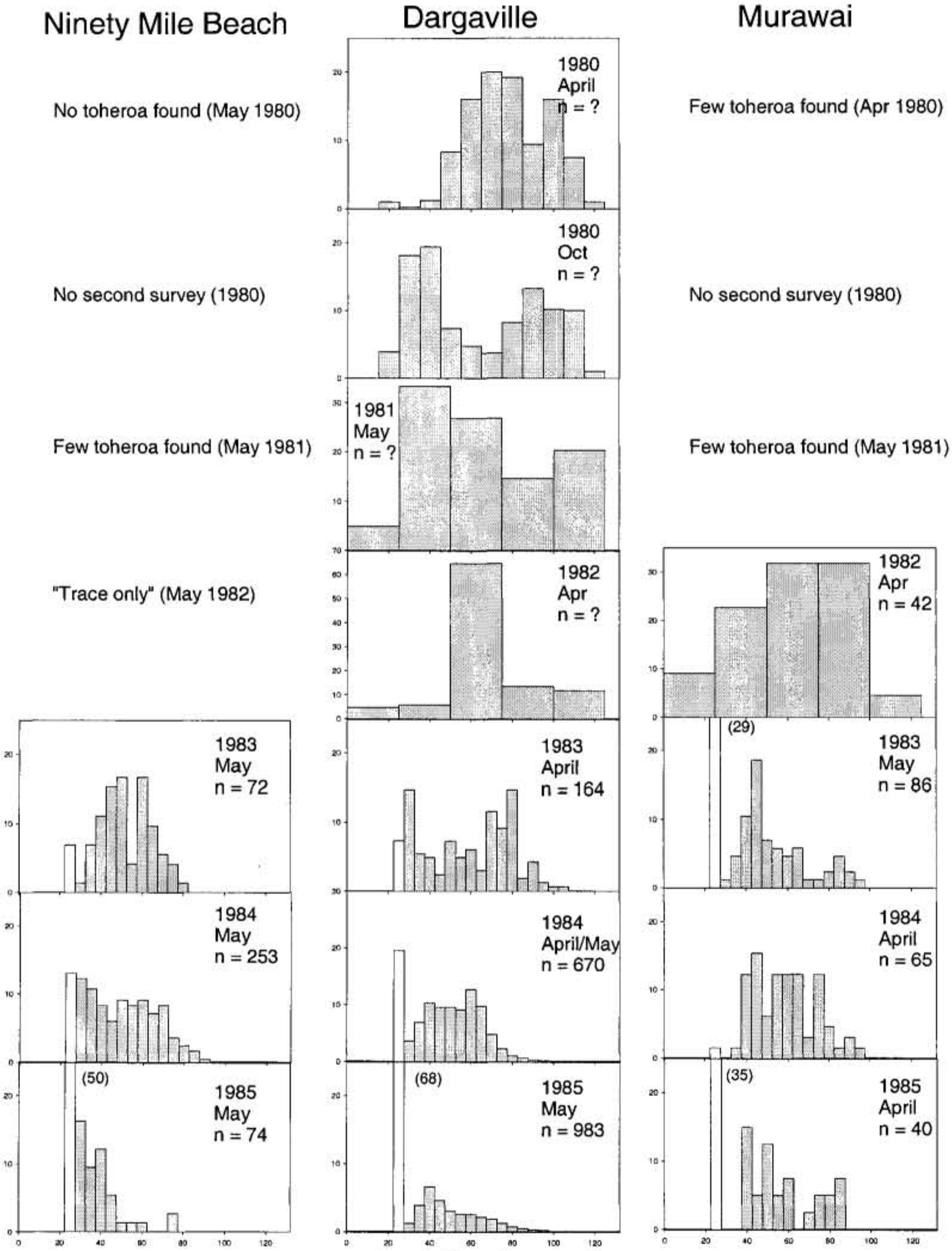

Figure 3 continued; 1980–85. Data from 1980 were found only in 10 mm increments, while data from 1981 and 1982 were recoverable only in 25 mm increments.

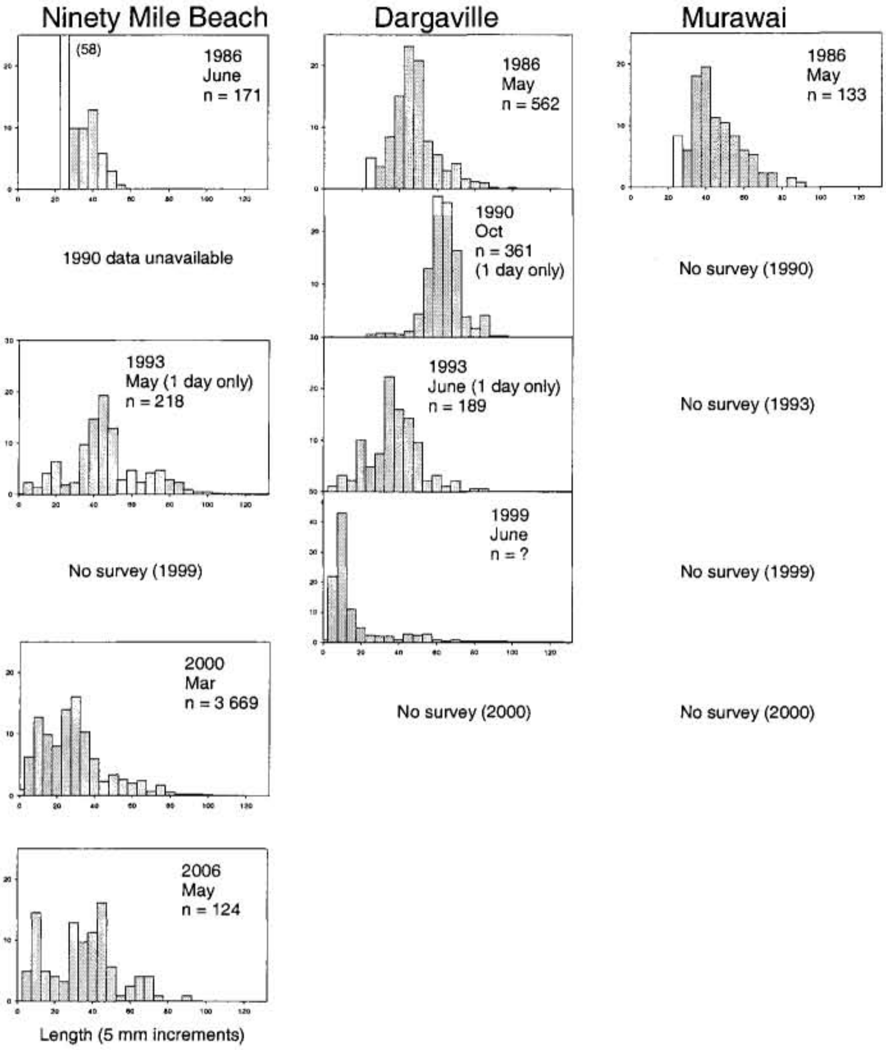

Figure 3 continued; 1986–2006.

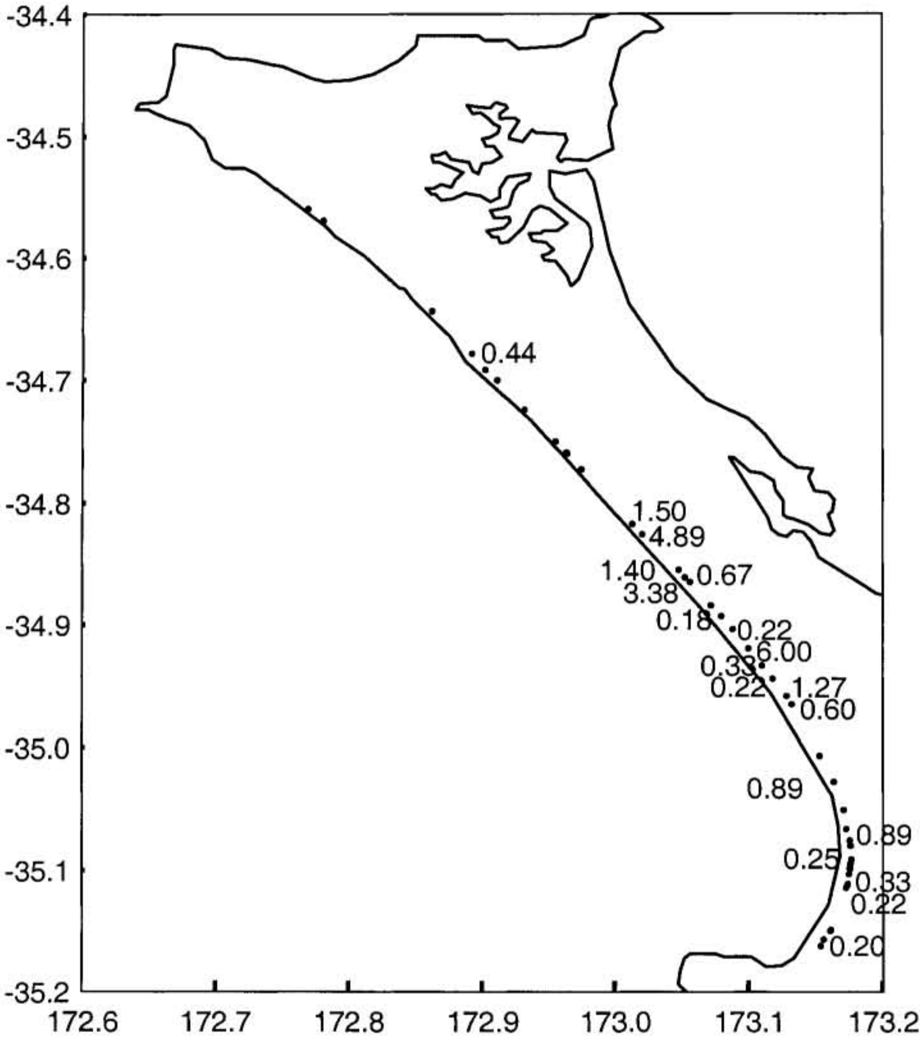

Figure 4: Toheroa densities along Ninety Mile Beach. Values are individuals per m², averaged across the full transect; where no value is given, no toheroa were sampled. Mismatches between the survey positions and the coast are due to inaccuracy in the base map.

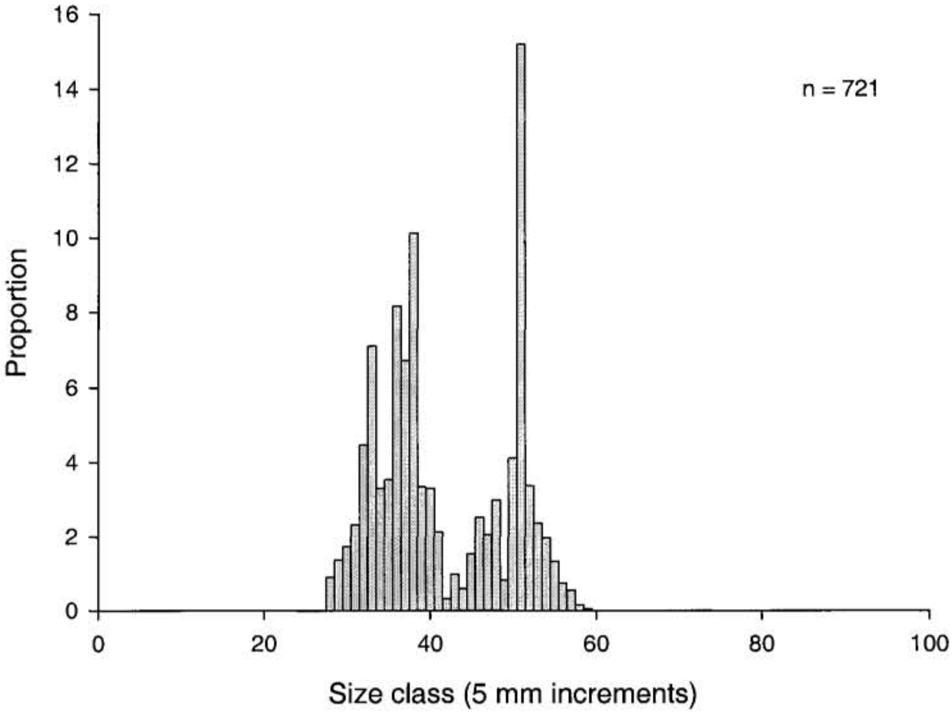

Figure 5: Length frequency of intertidal tuatua on Ninety Mile Beach, May 2006

Appendix 1: Historical toheroa population estimates for Ninety Mile, Dargaville, and Murawai Beaches. Estimates before 1957 are from Cassie (1955) and Redfearn (1974), those from 1962–71 from Greenway (1972), those from later years taken from various unpublished reports and memos, held at the Ministry of Fisheries' Auckland office. The 1999 Dargaville data come from Akroyd et al. (1999)s. Superscript letters denote the month in which a survey was undertaken; (^{M}, March; ^{Ma}, May; ^{J}, June; ^{Ju}, July; other letters as respective months). [1] denotes only toheroa over 3 inches (76 mm); [2] denotes only half of the beach having been surveyed.

Year	Ninety Mile Beach	Dargaville	Density (thousands) Muriwai
1933	11000-12000 [1]	–	–
1934	–	–	–
1935	–	–	–
1936	–	–	–
1937	–	–	15000
1938	–	9000	4000
1939	12000	–	–
1940	–	–	5000
1941	35000	–	5000
1942	–	–	5000 [1]
1943	–	–	5000 [2]
1944	scarce	–	–
1945	scarce	–	–
1946	6000	–	–
1947	–	–	3000 [2]
1948	very scarce	5000	10000&13000
1949	–	–	15000
1950	–	–	1000 [2]
1951	–	–	–
1952	–	–	8000
1953	–	–	–
1954	–	–	–
1955	–	10000	–
1956	–	–	–
1957	6200	–	–
1958	–	–	–
1959	–	–	–
1960	–	–	–
1961	–	–	–
1962	24992^{O}	20529^{S}	5181^{S}
1963	22081^{Ma}, 26200^{J}, 37048^{S}	$18142^{S,}$ 10866^{Ma}	4717^{J}, 8339^{S}
1964	22100^{Ma},15319^{O}	14837^{O}	7353^{F}, 12408^{F},600^{S}
1965	$1457^{J,}$ 3907^{O}	11774^{Ap}, 15365^{N}	1600^{M}, 3633^{O}
1966	$2314^{Ma,}$ 1901^{N}	3274^{Ap}, 14583^{O}	$5449^{Ap,}$ 3052^{O}
1967	538^{Ma}, 834^{N}	5090^{O}	2313^{Ap}, 3823^{O}
1968	1900^{Ma}, 6900^{N}	6300^{Ap}, 3400^{O}	6700^{Ap}, 2200^{O}
1969	7100^{Ma}, 9300^{N}	6500^{Ap}, 8100^{O}	2600^{O}

1970	18406[Ma], 41000[N]	11151[M]a, 8200[O]	2577[Ap], 700[O]
1971	10400[J]	3200[Ma]	1400[AP], 900[N]
1972	3700[J]	29980[J]	2100[Ma]
1973	700[J]	4328[J]	6695[J]
1974	300[J]	10750[Ma], 4446[O]	6674[J]
1975	30[J]	6135[Ma], 3907[O]	1003[J]
1976	0[J]	5639[Ma], 15492[O]	3300[J], 876[O]
1977	180 (first 20 miles)	12841[F], 8078[Ma], 8965[O]	444[J]
1978	30[J]	4699[Ap], 3700[O]	359[A]
1979	none found	3179[Ap]	792[A]
1980	none found	3700[Ma], 5500[O]	200[A]
1981	50[Ma]	4600[Ap]	20[Ma]
1982	20[Ma]	6300[Ap]	40[Ap]
1983	766[Ma]	2085[Ap]	908[Ma]
1984	2672[Ma]	7073[Ap/Ma]	686[Ap]
1985	781[Ma]	10380[Ma]	420[Ap]
1986	1806	5935	1404
1987	–	–	–
1988	–	–	–
1989	–	–	–
1990	–	–	–
1991	–	–	–
1992	–	–	–
1993	–	–	–
1994	–	–	–
1995	–	–	–
1996	–	–	–
1997	–	–	–
1998	–	–	–
1999	–	113000[J]	–
2000	51500[M]	–	–
2001	–	–	–
2002	–	–	–
2003	–	–	–
2004	–	–	–
2005	–	–	–
2006	8800[Ma]	–	–