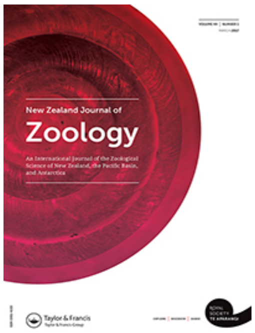

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RESEARCH ARTICLE

Evidence of absence is not proof of absence: the case of the New Brighton katipō

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ABSTRACT
The katipō is an endemic New Zealand spider that was previously common in the sand dunes at New Brighton. At sites on Banks Peninsula, katipō were detected under dried seaweed on the strandline 70% of the time. However, we detected no katipō among strandlines at New Brighton after 382 sampling visits. Incorporating these results into binomial and iterative Bayesian sampling models, it appeared highly unlikely that katipō still existed at New Brighton given so many non-detection events. However, when re-visiting the site, katipō were observed in the dunes at two locations, although they were still not found on the strandline. This specific habitat may be avoided at New Brighton due to high exposure to the prevalent strong easterly winds that occur at this site. The results emphasise that sampling models that use non-detection to indicate the likelihood of species absence can be highly specific to the sampling method used.

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KEYWORDS
New Zealand; non-detection; presence–absence; sampling effort; species distribution modelling

Introduction

For conservationists, the detection of a target species at a study site unequivocally confirms the presence of the species at that location at that time. However, non-detection of a species at a site does not, conversely, confirm its absence, because non-detection can transpire for a variety of reasons other than actual non-occurrence (Gu & Swihart 2004; Mackenzie 2005; McBride & Johnstone 2011). The frequency of 'false absences' can be influenced by multiple aspects of the survey design, such as sampling effort, sampling method and sampling frequency, and biological factors, such as life history of the species, seasonal patterns in abundance (or presence/absence) and the degree of spatial aggregation (Mackenzie 2005; Tikoca et al. 2016). Hence conclusions regarding the likelihood of absence of a species at a site must consider the number of consecutive samples that have produced no records, the degree of sampling effort used on each occasion and estimates of the probability of imperfect detection, which can be based on the frequency of detection at sites where the species is known to occur (Mackenzie et al. 2002; Mackenzie 2005; Barron et al. 2014).

The katipō (Theridiidae; *Latrodectus katipo* Powell, 1871) is a widow spider endemic to New Zealand (Vink et al. 2008). The species predominantly occurs in coastal sand dunes

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where it is found among grasses and under driftwood and tidal debris. Hann (1990) suggested that katipō numbers were decreasing in North Island, and katipō were found at only 46% of locations where they had been previously recorded by Patrick (2002). Although given protected status under the New Zealand Wildlife Act in 2010, it is believed that the national population of katipō is still declining (Sirvid et al. 2012).

In 1969, Smith (1971) found that katipō were common in the sand dunes at New Brighton near Christchurch, observing 187 specimens in 170 × 1 m^2 quadrats and locating 32 webs in a '10-m square'. Around 30 years later, Griffiths (2001) reported that katipō were still present at the southern tip of the dunes (South Spit) and also present in the dunes to the north of New Brighton at Bottle Lake Park. After this, Patrick (2002) found no katipō in the sand dunes at North New Brighton, and MacFarlane (2005) did not list katipō among the spiders he collected during his survey of invertebrates at New Brighton dunes for Christchurch City Council. Katipō were still present at South Spit in 2010 (CJ Vink pers. obs.) but in 2011 attempts at studying katipō at New Brighton using artificial cover objects were abandoned by researchers from Lincoln University as no specimens were found during initial survey work (VR Smith pers. comm.); these searches were made in the dunes around 500 m either side of New Brighton pier and South Spit was not searched.

In addition to basic hand searching, katipō have been surveyed by inspecting driftwood on the upper shore (e.g. Griffiths 2001) and by using 'artificial cover objects' (Lettink & Patrick 2006; Costall & Death 2010; Smith et al. 2014). Our study formed part of a larger investigation into spiders and other invertebrates occurring in the strandline habitat at New Brighton and around Banks Peninsula. Marine strandlines or 'wrack beds' consist of accumulations of loose seaweed and marine debris washed up on shore, which are then colonised by a wide range of littoral and terrestrial arthropod detritivores and their associated predators and parasites (Hodge & Jessop 1996; Hodge & Arthur 1997; Hodge & Williams 2007). Spiders are not uncommon in marine strandlines (Hodge & Vink 2006) and katipō have been observed under dried seaweed on the upper shore (S Hodge pers. obs.). A secondary aim of this larger study was to record katipō at whatever sites they occurred, and so confirm that katipō used the strandline or large pieces of dried seaweed for shelter and/or constructing webs.

Although katipō were recorded in the strandline at other locations, they were not recorded in the strandlines at New Brighton. By using the frequency of detection at other locations to estimate the probability of detection, we were able to predict the probability of absence of katipō at New Brighton given so many non-detection events. We then evaluated these predictions by revisiting New Brighton on three occasions from March to May 2016 and specifically searching for katipō both in the strandline and among dune vegetation.

Methods

Initial surveys

New Brighton sand dunes lie to the east of Christchurch, New Zealand. The dunes run approximately 10 km, from Beach Road in the north (43.486°S, 172.724°E) to the South Spit Reserve (43.561°S, 172.749°E). The flora is dominated by exotic plant species: marram grass (*Ammophila arenaria* (L.) Link), tree lupins (*Lupinus arboreus* Sims), purple ragwort (*Senecio elegans* L.) and large mats of ice plant (*Carpobrotus edulis* (L.) N.E. Brown).

The beach at New Brighton was visited 382 times between October 2011 and November 2013, at locations ranging from the car park near Beach Road in the north, to the seaward side of the South Spit Reserve. On each sampling visit, strandlines, dried seaweed and beach debris on the upper shore were searched by hand (by SH) for 30 minutes, and insects, arachnids and other arthropods were collected using a battery-operated aspirator. On the few occasions when field assistants were employed the searching time was shortened accordingly so that the total ‘person-search-minutes’ remained constant. As our survey formed part of a larger investigation of invertebrates occurring specifically in the strandline habitat, large pieces of driftwood were deliberately avoided.

A further 35 locations on Banks Peninsula, from Sumner beach (43.566°S, 172.759°E) in the north to Kaitorete Spit (43.827°S, 172.672°E) in the south, were visited a total of 153 times (by SH) between January 2012 and February 2015 (see Appendix). Each sampling event again consisted of 30 minutes of hand searching for arthropods, which was limited to the strandline, beach debris and dried seaweed.

Any katipō found were identified on site and allowed to return to the area where they had been observed. If katipō were recorded at a site then this was taken as ‘self-confirmation’ that the species occurred at this location, and the proportion of visits to that location in which katipō were observed was used to establish the probability of detection using this search method.

Binomial model

A simple measure of the likelihood of species presence, given a series of non-detection events, can be obtained by assuming that the number of species detections obtained from a given number of sampling events follows a binomial distribution (MacKenzie 2005). If we state that the probability of detection of a species, given that it is present, is denoted as $P_{\text{Detected} \mid \text{Present}}$, then the probability of non-detection is $P_{\text{Non-detected} \mid \text{Present}} = 1 - (P_{\text{Detected} \mid \text{Present}})$. In a simple binomial setting the probability of not detecting a species on N independent visits to a location where it actually occurs is therefore equal to $(P_{\text{Non-detected} \mid \text{Present}})^N$ (MacKenzie 2005); when N becomes large, then $(P_{\text{Non-detected} \mid \text{Present}})^N$ approaches zero. In this situation, given such a minute probability of obtaining so many non-detections if the species is present, the conclusion must be that the opposite situation is more likely, and the species is most probably absent from the site.

Bayesian model

A number of models estimating the continued likelihood of species presence after a given sampling effort utilise a Bayesian approach (e.g. Barron et al. 2011, 2014; McBride & Johnstone 2011). A Bayesian approach can be adopted in situations where the investigator has some initial idea regarding the likelihood of species presence, and this likelihood of occurrence is then modified in the light of subsequent non-detection events. In this situation the basic Bayesian equation can be written as:

$$P_{(\text{Present} \mid \text{Non-detected})} = \frac{P_{(\text{Non-detected} \mid \text{Present})} P_{(\text{Present})}}{P_{(\text{Non-detected})}} \tag{1}$$

The probabilities required for the analysis can be visualised using a probability tree (Figure 1A), where an initial estimate of the probability of the species being present is used, followed by an estimate of the probability of detection. By default, when the species is absent the probability of detection is zero and the probability of non-detection is equal to one (Figure 1B).

The initial likelihood of species presence can be considered as the initial prior probability, which produces a first posterior probability of presence after a single sampling event has resulted in non-detection. This initial posterior probability of species presence can then be considered the prior probability for the next sampling event, and so on, producing an iterative chain of events, which continues until all the non-detection occasions have been accounted for, and the final posterior probability of species presence is calculated.

In our modelling process, we set the probability of detection as that obtained from the Banks Peninsula field surveys (i.e. $P_{\text{Detected} \mid \text{Present}} = 0.7$) and used an initial uniform prior where there was an equal chance of katipō being present or absent ($P_{\text{Present}} = P_{\text{Absent}} = 0.5$). We then varied the prior probability of presence in steps of 0.2 to represent that it was ‘very likely’ that the species was present ($P_{\text{Present}} = 0.9$) to ‘very unlikely’ the species was present ($P_{\text{Present}} = 0.1$).

Model evaluation survey

The initial results from the New Brighton survey and the modelling processes suggested that it was highly unlikely that katipō were present at New Brighton. MacKenzie and Royle (2005) suggested that when $P_{\text{Detected} \mid \text{Present}}$ is thought to be > 0.5 then at least three visits should be made to a site in order to determine presence or absence. Therefore, as $P_{\text{Detected} \mid \text{Present}}$ in our case was equal to 0.7, to evaluate the accuracy of the model predictions New Brighton was revisited on three separate days (by CJV), approximately one month apart (from March to May 2016).

On each sampling visit, a 30 minute search was performed among strandline material, once at South Spit and once at another location. To assess whether the results of the models might be applicable to the New Brighton site as a whole, or were specific to only the strandline habitat, a second 30 minute search was then performed among the actual dune vegetation. This second search was performed inland from where the strandline had been investigated.

In these model evaluation sampling visits, the focus was primarily on recording the presence of katipō, and no specimens of other arthropod species were collected on these occasions. Katipō recorded were classified as adult males, adult females or subadults and returned to the location where they had been observed.

Results

Initial survey

No katipō were recorded during any of the 382 sampling events performed in the strandlines at New Brighton during the initial invertebrate survey. This included six visits to strandlines near the fore dunes near South Spit Reserve where we had previously observed katipō in 2010.

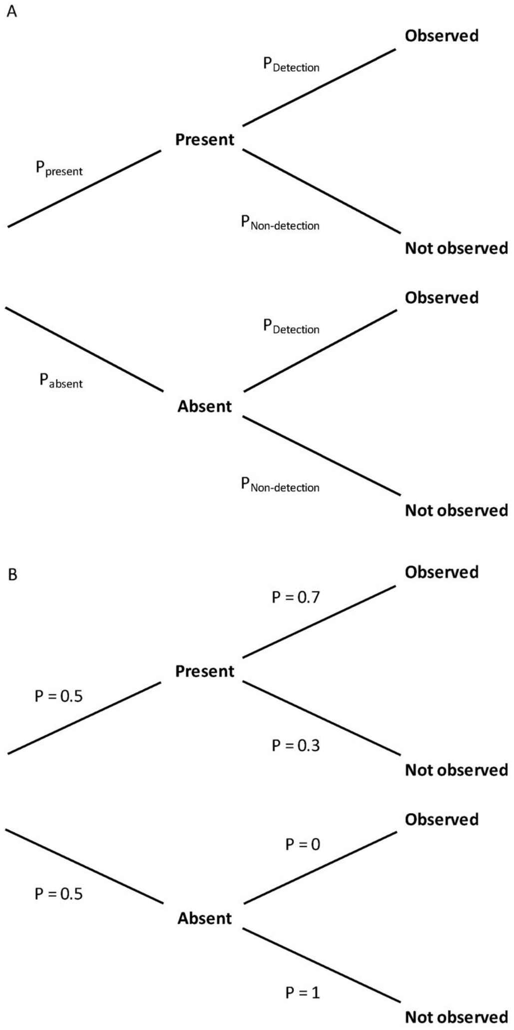

Figure 1. Probability trees. **A,** Schematic of the detection process of a species over the course one sampling event. **B,** The process where an initial uniform prior probability of presence is used ($P_{\text{Present}} = P_{\text{Absent}} = 0.5$) and the detection probability is set at $P_{(\text{detection} \mid \text{present})} = 0.7$.

However, we did record mature adult katipō in strandlines or under dried seaweed at three sites on Banks Peninsula: Le Bons Bay (43.742°S, 173.096°E), Okains Bay (43.694°S, 173.061°E) and Kaitorete Spit (43.827°S, 172.672°E). Katipō were observed on all four visits to Le Bons Bay, two of the four visits to Okains Bay and one of the two visits to Kaitorete Spit. Therefore, katipō were recorded in seven of the ten visits to sites where their presence was confirmed (as part of this survey). Hence, the probability of observing katipō given they are present can be expressed as:

$$P_{(\text{Detection} \mid \text{Present})} = 7/10 = 0.7 \tag{2}$$

and conversely the probability of not finding katipō given they are present expressed as:

$$P_{(\text{Non-detection}\,|\,\text{Present})} = 1 - 0.7 = 0.3 \tag{3}$$

Binomial model

The probability of non-detection calculated above can now be used in a binomial setting to give an indication of how likely it is that katipō are present at New Brighton. For all 382 samples taken over the 3 years, the probability of recording no katipō if they were actually present can be obtained as:

$$P_{(\text{Not observing at all}\,|\,\text{Present})} = 0.3^{382} = 1.82 \times 10^{-200} \tag{4}$$

Katipō abundance or activity is thought to be affected by season (Smith et al. 2014). As the katipō on Banks Peninsula were mainly recorded during the summer months, for consistency if only the 190 New Brighton 'summer samples' (October–March) are considered the probability of recording no katipō given they were present becomes:

$$P_{(\text{Not observing in summer}\,|\,\text{Present})} = 0.3^{190} = 4.50 \times 10^{-100} \tag{5}$$

Finally, if we consider only those samples from South Spit, where we last observed katipō in 2010, the probability of recording no katipō in the six samples taken at this specific location given that they are still present is:

$$P_{(\text{Not observing at South Spit}\,|\,\text{Present})} = 0.36 = 0.000729 \tag{6}$$

So, when considering samples along the whole beach at New Brighton, the probability of obtaining so many non-detection events, both throughout the year and only in the summer months, is essentially equal to zero. The probability of recording no katipō in the strandline in all six samples from South Spit produced a probability of $P < 0.001$. Hence, in all cases we examined, the binomial model suggested that the likelihood of continued presence of katipō at New Brighton was extremely small.

Bayesian model

By setting the probability of non-detection as $P_{\text{Non-detection}\,|\,\text{Present}} = 0.3$, the Bayesian process follows that illustrated in Figure 1(b). If a uniform prior is used ($P_{\text{Present}} = P_{\text{Absent}} = 0.5$) then the probability of observing katipō after one sampling event is equal to $(0.5 \times 0.7) + (0.5 \times 0) = 0.35$, whereas the probability of not observing the spider is equal to $(0.5 \times 0.3) + (0.5 \times 1) = 0.65$. Substituting these values into Equation 1 produced a first posterior probability of presence of 0.231. This value can then be used as the prior probability of presence in the next sampling event, producing a subsequent posterior probability of presence of 0.083, and so on through subsequent sampling events (see Figure 2).

From our simulations, it became apparent that the initial prior distribution, indicating likelihood of presence of the species at a location, becomes less important the more sampling cycles are considered (Figure 2). With $P_{\text{Non-detection}\,|\,\text{Present}} = 0.3$, after six non-detection events the final probability of the species being present was always low regardless of the initial prior ($P_{\text{Present}} < 0.002$ when $P_0 = 0.9$; Figure 2). Hence, even if we had high expectations that the species would be present at South Spit before the survey, given that the six samples from this location produced no specimens, the probability of continued presence at the site must be considered very low.

Model evaluation survey

In the three visits made to South Spit in 2016, no katipō were located in the strandline. However, katipō were recorded in the sand dunes at South Spit on all three occasions, with 35 specimens being observed during a total of 90 minutes of searching (Table 1).

With regard to the other locations that were searched, two katipō were observed in the dunes near Penguin Street (43.545°S, 172.748°E), although none were found in the dunes at the locations further north, Jervois Street (43.518°S, 172.736°E) and Leaver Terrace (43.493°S, 172.726°E) (Table 1). No katipō were found in the strandlines at any of these other locations (Table 1).

The absence of katipō in all six of the strandline searches reinforced the predictions of the models that suggested it was highly unlikely that katipō still occurred at New Brighton or South Spit. However, katipō presence in four of the six dune vegetation searches indicated that predictions of absence were clearly incorrect when considering the site as a whole.

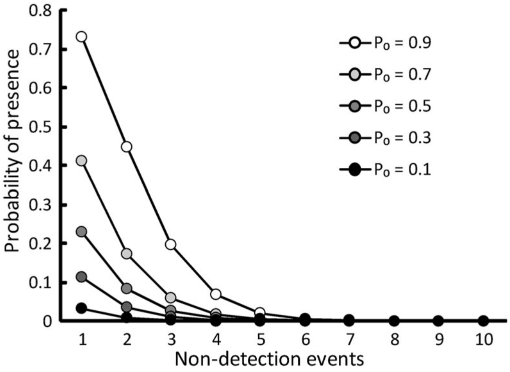

Figure 2. Posterior probability of the presence of a species after a given number of non-detection events. P_0 is the initial (prior) probability of the species being present and the probability of non-detection was set to 0.3 based on our findings with katipō. (see *Methods* for details of Bayesian process).

Table 1. Number of katipō recorded at New Brighton during 30 minute hand searches of sand dunes and strandlines in 2016. The street name in parentheses indicates the specific location for the 'Other location' that was sampled on that date.

		South Spit			Other location		
Date	Habitat	Males	Females	Sub-adults	Males	Females	Sub-adults
3 Mar 2016	Dunes	4	5	4	1	1	0
(Penguin St)	Strandline	0	0	0	0	0	0
10 Apr 2016	Dunes	4	3	5	0	0	0
(Jervois St)	Strandline	0	0	0	0	0	0
6 May 2016	Dunes	0	5	5	0	0	0
(Leaver Tce)	Strandline	0	0	0	0	0	0
Total	Dunes	8	13	14	1	1	0
	Strandline	0	0	0	0	0	0

Discussion

The searches of the sand dunes confirmed the continued presence of katipō at New Brighton. From this limited survey the species appears to be relatively abundant at South Spit, although no specimens were observed further north at the dunes in front of Jervois Street or Leaver Terrace, which are both in areas where human activity is high. The potentially restricted distribution of katipō in the dunes may explain why they were not recorded by Patrick (2002) and MacFarlane (2005) and further survey work is required to provide a more detailed picture of the extent of katipō occupation of the dune system.

Recent attempts have been made to introduce more native New Zealand plant species into the dune system, such as pingao (*Ficinia spiralis* (A. Rich) Muasya & de Lange) and spinifex (*Spinifex sericeus* R.Br.) on the foreshore, and cottonwood (*Ozothamnus leptophyllus* (G. Forst.) Breitw. & J.M. Ward), harakeke (*Phormium tenax* J.R. Forst. & G. Forst.) and ngaio (*Myoporum laetum* G. Forst.) to the rear of the dunes. It has been suggested that katipō prefer areas of native grass species over marram because the latter grass species occurs in swards that are too dense, which can hinder prey movement (Smith et al. 2014). However, Smith (1971) found that although katipō at New Brighton were not abundant in dense marram, they were actually more abundant in medium density marram compared with sparse marram and pingao. Hence, in addition to native plantings, there may be potential to manage the site in terms of promoting the extension of katipō range by thinning marram rather than removing it all together. Similarly, Hetherington and Wilson (2014) reported no negative association between katipō and tree lupin, another abundant non-native plant at New Brighton, so mass removal of this species may also have no immediate impacts on katipō abundance.

A number of reasons may explain the absence of katipō from the strandlines at New Brighton when considering that they were observed in this habitat at other locations. The invasive spider *Steatoda capensis* Hann, 1990 (Theridiidae) was relatively common in the strandlines at New Brighton, being observed on 21% of the 382 visits. Although Hann (1990) and Costall and Death (2009) indicated that katipō might be displaced by *S. capensis*, Costall and Death (2010) subsequently reported no relationship between *S. capensis* and katipō at three locations on North Island. Hetherington and Wilson (2014) also found no negative association between katipō and *S. capensis* at Kaitorete Spit over a large spatial scale, and over multiple years. Hence, although we cannot rule out this possibility, the suggestion that *S. capensis* aggressively displaces katipō from the strandlines at New Brighton would be speculative at this stage.

Smith (1971) found that katipō were much more common on north-facing and, especially, west-facing slopes at New Brighton. This result may arise from the spiders seeking sunnier and warmer locations to ensure that their egg sacs mature (Forster & Kingsford 1983) and to avoid the regular easterly winds that cause major disturbance to loose sand. An avoidance of east-facing slopes would tend to prohibit katipō from the seaward-facing slopes at New Brighton, so making their chances of reaching the strandline somewhat negligible. The beaches at Okains Bay and Le Bons Bay, where katipō were observed in the strandlines, are much more sheltered, and the spiders may not be as prone to avoid the fringes of the dunes at these locations. Additionally, the strandline material we searched at Le Bons Bay, Okains Bay and Kaitorete Spit appeared to have been present for some time before the sampling visit, often at the extreme upper shore or even among the dune fringe. At New Brighton, especially in the northern part of the dunes, the high tides often reached the dunes, so wetting strandline material already present or depositing fresh material, and generally creating a much less stable habitat for spiders to occupy.

Even though the model estimates based on non-detection in over 380 searches of strandline material provided very strong evidence that katipō were absent from New Brighton, the recording of multiple specimens in the sand dunes blatantly proved that the opposite situation was the case. This discrepancy is clearly due to the differences between the sampling method used in the development of the models (strandline searches) and the sampling methods used in the model evaluation (strandline and dune searches). From the model evaluation surveys, the prediction that katipō were absent in the strandline habitat at New Brighton would actually appear to be correct. However, the model evaluation surveys also illustrate that the evidence of absence obtained from the initial survey should only be applied to the actual habitat used in the model development, and that the predictions of absence are not applicable to other katipō habitats that may occur at this, or any other, site.

As with many ecological modelling endeavours, the production of the models and analysis of their effectiveness has led to a re-evaluation of how parameters are estimated and the specific conditions under which the predictions of the models apply. For example, the sand dune searches at South Spit suggested that the probability of detection using 30 minute hand searches was 100% in this habitat using this method. However, over the whole dune system the power of detection was only 66% and so the estimate of this critical parameter is dependent upon what is considered a meaningful spatial scale. A number of studies have used artificial cover objects to study katipō populations (e.g. Lettink & Patrick 2006; Costall & Death 2010; Smith et al. 2014). There may be potential to adapt the methods developed in this paper to situations where the 'probability of detection' can be estimated by the frequency of occupation of artificial cover objects at locations where katipō are found. This could then lead to decisions on how many unoccupied artificial cover objects are required before concluding it is more than likely katipō are truly absent, rather than just undersampled.

Once formulated, these sampling models are fairly easy to implement and are useful for providing meaningful estimates on how likely it is that a target species occurs at a given location, given that a certain sampling effort has resulted in no detections (MacKenzie & Royle 2005). Ultimately, by testing the models and identifying their strengths and weaknesses, a better understanding is achieved both of the modelling process and the natural history of the ecological system they are attempting to portray.

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Appendix

Lists of sites where strandlines were sampled as part of the initial invertebrate survey. Figures in parentheses indicate the number of visits made to that location.

Akaroa (9); Allandale (8); Barry's Bay (5); Birdling's Flat (6); Boulder Bay (2); Camp Bay (2); Cass Bay (3); Charteris Bay (4); Childrens Bay (4); Corsair Bay (9); Decanter Bay (2); Diamond Harbour (2); Duvauchelle (8); Flea Bay (1); Govenors Bay (7); Kaitorete Spit (2); Le Bons Bay (4); Little Akaloa (7); Lyttleton (1); Okains Bay (4); Otanerito Bay (1); Pigeon Bay (3); Port Levy (2); Purau (4); Quail Island (12); Rapaki (7); Robinsons Bay (4); Sleepy Bay (1); Stony Bay (1); Sumner (11); Takamatua (5); Taylors Mistake (3); Te Oka Bay (1); Tumbledown Bay (4); Wainui, (4).