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Manatū Ahu Matua

# Can otolith chemistry predict the natal origins of grey mullet (*Mugil cephalus*)?

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## EXECUTIVE SUMMARY

**Morrison, M.A.; McKenzie, J.R.; Gillanders, B.M.; Tuck, I. (2016). Can otolith chemistry predict the natal origins of grey mullet (*Mugil cephalus*)?**

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Juvenile grey mullet from the 2010 year class were sampled from 76 likely nursery areas (estuarine areas) in northern New Zealand (GMU 1), and 573 otoliths analysed for their chemical composition. An initial multivariate (ANOSIM) test of the otolith data from a subset of 24 estuarine areas found a high number of significant differences between these areas, however, only the Waikato River was uniquely different to all other groups. Quadratic Discrimination Analysis (QDA), was used to assign otoliths to their harbour of capture based on their chemical signatures. To meet the QDA analysis requirements it was required to group the otolith data into seven spatial regions. Pair-wise ANOSIM tests of these regions found a high number of significant differences, however, only the Kaipara Harbour and the Bay of Plenty regions were uniquely different from all other groups. The QDA resultant allocation (confusion) table produced mixed results, with 47% of fish correctly assigned to their region of origin, the highest correct allocation (72%) being for East Northland. Further dividing the QDA data into separate west and east coast analysis data sets, each with an adjacent spatial group from the most northern estuaries of the other coast, improved the classification success for all of the west coast groups (range 28 to 74%), but less so for the four east coast groups (range 26 to 74%), with the Hauraki Gulf (62%) and East Northland being the most successful (74%). An assessment was also made as to the expected improvement in QDA success through increasing the number of otoliths used to inform the QDA. The results suggest that only marginal gains in the resolving power of the QDA would be achieved.

Bootstrapping was used to derive 95% confidence limits over a range of true sample proportions from each natal estuary/region as derived from QDA. Bootstrapping thus allowed for the relative power of the QDA to be assessed under finite sampling. The bootstrap results suggest that the ‘all GMU 1’ QDA had adequate power to predict the natal origin of a 500 otolith sample comprised of 90% or more east Northland origin mullet. The ‘east coast only’ QDA had adequate power given a 500 otolith sample of better than 90% east Northland or Hauraki Gulf natal origin grey mullet.

Although the 2010 natal otolith datasets and QDA analytical procedures provide some power to identify a relatively pure sample of adult east Northland 2010 natal origin grey mullet collected anywhere within GMU 1 overall, the ability of these data to distinguish different nursery areas and assign adult grey mullet to their natal region using otolith chemistry was poor, with insufficient precision to be considered useful for exploring the stock relationships of grey mullet. The conclusion of this report, and of the Northern Inshore Finfish Working Group, is that sampling of adult mullet to match otolith chemistries with the juveniles, for large scale stock discrimination, is not recommended. The potential remains for useful work at finer spatial scales, although outside the focus of the GMU200901 project.

This includes the investigation of source-sink dynamics at finer spatial scales, through if adults are to be explicitly sampled from the 2010 year class, then the time window for sampling is limited to the next 2–3 years (as from 2016). Additionally, a significant adult grey mullet biomass exists in freshwater populations (lakes and rivers) whose recruitment origins and linkages to marine populations remain ambiguous. The few juvenile fish able to be found in the lower Waikato River suggest that identifying any freshwater nursery derived adult fish should be relatively easy (assuming that such nurseries exist). Ongoing work on the otolith chemistry of adult fish (as collected and analysed through the MBIE CCM programme), combined with some of the juvenile data reported on here, will help address some of these (and other) questions.

# 1. INTRODUCTION

Grey mullet (*Mugil cephalus*) are a globally distributed species, found in temperate and sub-tropical areas of both hemispheres. Livi et al. (2011) assessed grey mullet genetics globally from 14 regions across the northern and southern hemispheres, including eastern and western Australia (but not New Zealand). They reported a deep genetic divergence between the different regions, indicating very low connectivity between the different populations. The eastern and western Australia populations were quite distinct from each other. Work by Durand et al. (2012) on global genetics included three grey mullet individuals from two New Zealand locations (Waikato and Patea Rivers), and suggested that one of these individuals had a cluster affinity to New Caledonia samples (see figure 5 of Whitfield et al. (2012)), while the other two (one each from the two rivers) had a different cluster affinity with eastern Australia. Intensive New Zealand scale grey mullet genetics work currently underway is expected to significantly advance our understanding in this region (Jiménez, in prep.).

In New Zealand grey mullet are largely restricted to more northern temperate waters, with the main fisheries being in the upper half of the North Island, although the species distribution extends at least as far south as the top of the South Island. Grey mullet have been reported from Ahuriri Estuary, Napier (Kilner & Akroyd 1978), and Porirua Harbour and Makara Stream in the Wellington region (Jellyman 1977, Jones & Hadfield 1985, Strickland & Quarterman 2001). Recent targeted sampling has also found them in the Patea River (South Taranaki), the Hutt River/Wellington Harbour, Lake Wairarapa, and at several upper South Island locations (Blenheim, inner Marlborough Sounds, and Nelson areas) (Morrison et al., unpubl. data).

Virtually all commercial fisheries catch is taken in the upper North Island, with negligible amounts landed outside of that region. That northern fishery (GMU 1) is managed as one discrete zone under a single annual commercial Total Allowable Catch (TAC). Most fish are taken from large estuaries and embayments, dominated by the Manukau and Kaipara estuaries on the west coast, and Rangaunu Bay and the Firth of Thames on the east coast. Lesser but still significant quantities of grey mullet are also taken from other North Island estuaries and coastal bays. A freshwater component was also until recently taken from the Waikato River, but with the retirement of freshwater commercial fishers, that river system is no longer commercially fished. Freshwater-caught fish also have a less preferred market status compared to marine-caught fish due to taste and texture differences.

The commercial grey mullet fishery is worth approximately NZ $2.5 million per annum (http://www.option4.co.nz/Fisheries_Mgmt/documents/GreyMullet.pdf). Most of the catch is sold locally, principally as bait for recreational fishers. The average annual commercial catch from GMU 1 over the last five fishing years (2009–2014) has been about 854 tonnes, which consistently falls short of the TAC of 1006 t (although catch has ranged from 746 to 981 t over that time period) (MPI 2015). Annual commercial catches from GMU 1 have all been markedly lower than the annual TAC since the inception of the Quota Management System (QMS) in 1986 (MPI 2015).

Recreational fishing surveys carried out on a national basis indicate that grey mullet is not a major recreational species (Wynne-Jones et al. 2014). However, by virtue of the easily accessible habitats in which it is found, it is a species of high ‘social’ value, particularly with Maori. Many northern iwi regard North Island estuaries and the rivers as sacrosanct and the fish that live in these environments a fundamental component of their spiritual value. Some iwi believe many harbour and river fish stocks, including grey mullet, are in decline. These iwi commonly cite environmental mismanagement and over-fishing as principal causes. In recent times, issues of grey mullet availability in various North Island bays and estuaries have resulted in conflict between the commercial and non-commercial sectors.

Conflicts surrounding grey mullet have been exacerbated by a lack of definitive scientific knowledge of New Zealand grey mullet stock dynamics. A major source of uncertainty relates to the degree of spatial separation within GMU 1. Evidence for stock separation within GMU 1 comes largely from CPUE analyses (Watson et al. 2005, McKenzie & Vaughan 2008); these analyses have found different abundance trends in component estuaries and regions. These CPUE results indicate that the stock structure and distribution of grey mullet within GMU 1 is likely to be complex. It is not known to what degree fish move between the various estuaries, and broader areas, within GMU 1. Given this lack of knowledge, at what spatial scale GMU 1 should optimally be managed remains unclear; whether it should be managed as one large highly inter-connected stock, or as a series of distinct stock areas with only limited fish interchange over management relevant time-scales is unknown.

Otolith chemistry analysis has been successfully applied on a number of coastal and estuarine fish stocks to identify important natal areas and to determine the degree of spatial mixing in the adult population as a whole (e.g. Gillanders & Kingsford 1996, Gillanders 2002, Reis-Santos et al. 2013). Grey mullet are a prime candidate for the successful use of such methodologies, as they are known to be heavily reliant on estuarine environments during their early juvenile life-stages. Within these environments, they are strongly associated with specific habitat types, including mangrove forests and (some) intertidal seagrass meadows at very small sizes (20–50 mm), and with the turbid, muddy tidal flats at slightly larger juvenile sizes (50–150 mm), before becoming more widely roaming as adults (Morrison et al. 2002, Francis et al. 2005, Morrison 2006, Morrisey et al. 2007, Morrison et al. 2014a–d). Given this life-history, and assuming that the chemical environments of the different natal areas vary, it would be expected that juvenile grey mullet would be likely to show distinct chemical signatures representative of their natal habitat. A comparison of adult grey mullet otolith chemical signatures against a 'reference library' of known origin juvenile grey mullet should therefore provide good information on the degree of mixing across stock areas (if any) relative to juvenile nursery grounds, given a robust sampling design, and the existence of clear spatial differences in otolith chemistry.

Here we report on the collection of juvenile grey mullet, and the subsequent analysis of their otoliths to assess whether meaningful multivariate element discriminations can be made between different spatial zones across the extent of GMU 1.

**Overall objectives**

1. To determine the level of spatial mixing and connectivity of grey mullet (*Mugil cephalus*) populations using otolith microchemistry.

**Specific objectives**

1. To collect and analyse the chemical composition of grey mullet otoliths.
2. To analyse the otoliths collected under Objective 1 to determine if the samples can be spatially separated.

## 2. METHODS

### 2.1 Selection of estuaries

In the project brief contracted with the Ministry of Primary Industries, eight areas and estuaries were targeted for sample collections (Table 1; Figure 1). These were considered to be most likely key nursery areas, in terms of providing the majority of recruitment to the fisheries. The Bay of Plenty was excluded from sampling by MPI, as that region supported only low fisheries catches, and was considered to be relatively unimportant.

**Table 1: Target estuaries and fish sample sizes specified in the GMU200901 contract.**

| Estuaries within regions | Number of sites | Fish target per site | Total target per harbour |
|---|---|---|---|
| *West Coast North Island* | | | |
| Hokianga Harbour | 3 | 10 | 30 |
| Kaipara Harbour | 3 | 10 | 30 |
| Manukau Harbour | 3 | 10 | 30 |
| Raglan Harbour | 3 | 10 | 30 |
| *East Northland* | | | |
| Rangaunu Harbour | 3 | 10 | 30 |
| Bay of Islands | 3 | 10 | 30 |
| *Hauraki Gulf* | | | |
| Firth of Thames | 3 | 10 | 30 |
| | | Total fish | 240 |

The opportunity to expand on and enhance these target collections, and to include additional harbours and estuaries (Figure 1; Table 2), became available through linking this project to work in the MBIE 'Coastal Conservation Management' (CCM) (CO1X0907) programme. The CCM programme is looking at identifying grey mullet nursery habitats more broadly across northern New Zealand, including their spatial variability, the potential role of source-sink dynamics in some selected locations, and the use of otolith chemistry as a potential marker for finer scale fish movement/connectivity.

Potential grey mullet nursery areas were identified using Google Maps, with the lower spatial extent cut-off being very small tidal creeks that emptied directly to the sea. Candidate nursery areas were then visited by field teams, who searched for and captured juvenile fish at likely sites within a given estuary. Sampling effort (number of sites per estuary) was driven largely by the size of the estuary, and the number of sub-catchments with associated freshwater drainage emptying into an estuary. Sites were located so that each was downstream of an adjacent sub-catchment, on the assumption that by sampling as many sub-catchments as possible, this would capture the greatest likely variation in grey mullet otolith chemistry for any given estuary. This was moderated slightly by whether suitable juvenile grey mullet habitat existed adjacent to a given sub-catchment; some smaller sub-catchment freshwater export points emptied straight out onto clearer water, sandy habitats, where juvenile grey mullet were always absent (a number were assessed). Smaller estuaries and creeks which emptied straight to the sea were sampled at one site only given their linear nature.

A set of 'core' estuaries were subsequently chosen for the full statistical analysis of juvenile grey mullet otoliths (Figure 1; Table 2). These core estuaries were chosen using the following 'rules of thumb'.

- They contained sufficient habitat extent to hold a meaningful juvenile grey mullet population in terms of possible contributions to the adult population. This excluded many small creeks and tidal inlets which opened directly to the open coast, e.g. Brodies Creek, Parapara River, Ruakaka, Waipu, and Pakiri Beach 1 & 2. We note that the simple areal extent of a harbour as viewed on a map does not necessarily equate to a large grey mullet habitat area: much of the area may be intertidal with only limited adjacent subtidal holding areas; and/or the water clear and the seafloor sand; the latter are environmental conditions in which juvenile mullet tend to occur in only low numbers, or not at all. Several (of many) examples included the Houhora, Mangawhai, Whangateau, Coromandel, Whangapoua, and Purangi estuaries, where the small numbers of fish present occurred in very limited parts of low tide pools and channels.

- The Waikato River was an exception, in that while juveniles were rare and only nine 0+ juveniles were captured in two days of searching; it held large numbers of adult fish. While we suspect it is a population sink for fish which have originated as juveniles in other estuaries, we included juveniles in the analysis given its importance to adult populations.
- The Bay of Plenty was not included as part of the GMU200901 objectives: however we included Tauranga Harbour given the presence of relatively common juveniles in its various tidal arms, and the overall relatively large extent of possible grey mullet habitat.

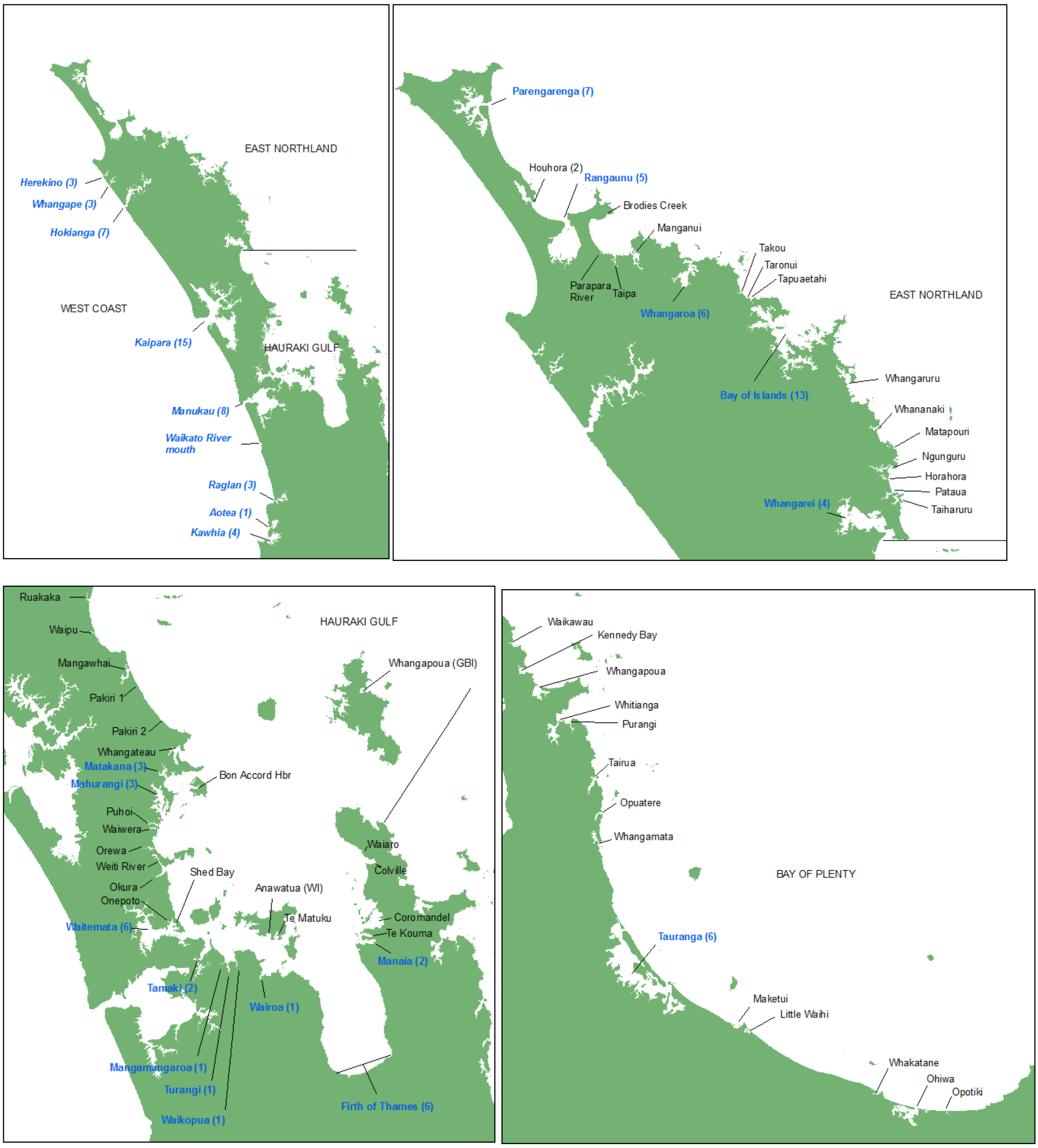


**Figure 1: Estuaries sampled by region. Note that the maps vary in scale. Core estuaries used in statistical analyses are bolded blue, and the number of sites sampled in brackets.**

**Table 2: Summary of grey mullet processed for otolith chemistry. n, number of fish processed for otolith chemistry (not the number of fish collected); *, additional sites added for potential MBIE source-sink work; ¥, too few fish caught for analysis. Grey shaded locations are those used for the statistical analysis of otolith chemistry.**

| Estuaries/bays | # Sites | n |
|---|---|---|
| **West Coast** | | |
| Herekino* | 3 | 15 |
| Whangape* | 3 | 15 |
| Hokianga | 7 | 35 |
| Kaipara | 15 | 75 |
| Manukau | 8 | 40 |
| Waikato River | 1 | 5 |
| Raglan | 3 | 15 |
| Aotea | 1 | 10 |
| Kawhia | 4 | 20 |
| | | |
| **East Northland** | | |
| Parengarenga | 7 | 35 |
| Houhora | 2 | 10 |
| Rangaunu | 5 | 25 |
| Brodies Creek | 1 | 5 |
| Parapara River | 1 | 5 |
| Taipa | 1 | 5 |
| Manganui | 1 | 5 |
| Whangaroa* | 6 | 30 |
| Takou | 1 | 5 |
| Taronui | 1 | 5 |
| Tapuaetahi | 1 | 5 |
| Bay of Islands | 13 | 65 |
| Whangaruru | 1 | 5 |
| Whananaki | 1 | 5 |
| Matapouri | 1 | 5 |
| Ngunguru | 1 | 5 |
| Horahora | 1 | 5 |
| Pataua | 1 | 5 |
| Taiharuru | 1 | 5 |
| Whangarei | 4 | 20 |

| | # Sites | n |
|---|---|---|
| **Greater Hauraki Gulf** | | |
| Ruakaka | 1 | 5 |
| Waipu | 1 | 5 |
| Mangawhai | 1 | 5 |
| Pakiri Beach 1 | 1 | 5 |
| Pakiri Beach 2 | 1 | 5 |
| Whangateau* | 4 | 20 |
| Whangapoua (Great Barrier Island) | 1 | 5 |
| Wairahi Bay (Great Barrier Island) | 1 | 5 |
| Kaitoke (Great Barrier Island) | 1 | 5 |
| Bon Accord (Kawau Island) | 1 | 5 |
| Matakana | 3 | 15 |
| Mahurangi | 1 | 15 |
| Puhoi | 1 | 5 |
| Waiwera | 1 | 5 |
| Orewa | 1 | 5 |
| Weiti River | 1 | 5 |
| Shed Bay (Waitemata Harbour) | 1 | 5 |
| Onepoto Crater (Waitemata Harbour) | 1 | 5 |
| Waitemata | 6 | 30 |
| Anawatua (Waiheke Island) | 1 | 5 |
| Te Matuku (Waiheke Island) | 1 | |
| Tamaki | 2 | 10 |
| Mangamangaroa (Whitford, Auckland) | 1 | 5 |
| Turanga (Whitford, Auckland) | 1 | 5 |
| Waikopua (Whitford, Auckland) | 1 | 5 |
| Wairoa | 1 | 5 |
| Firth of Thames | 6 | 29 |
| Manaia | 2 | 10 |
| Te Kouma | 1 | 4 |
| Coromandel¥ | 1 | 1 |
| Colville | 1 | 5 |
| | | |
| **Bay of Plenty** | | |
| Waikawau | 1 | 5 |
| Kennedy Bay | 2 | 10 |
| Whangapoua* | 5 | 25 |
| Whitianga | 2 | 10 |
| Purangi | 1 | 5 |
| Tairua | 1 | 5 |
| Opoutere | 1 | 5 |
| Whangamata | 2 | 10 |
| Tauranga North | 1 | 5 |
| Tauranga South | 5 | 25 |
| Otahu Estuary | 0 | Absent |
| Maketu | 2 | 10 |
| Little Waihi¥ | 0 | Absent |
| Whakatane | 1 | 5* |
| Ohiwa | 3 | 15 |
| Opotiki | 1 | 5 |

## 2.2 Physical sampling methods

Juvenile grey mullet (0+, <100 mm) are constrained in their habitat use to the upper areas of estuaries, often in proximity to mangrove forests (a known limited exception is low densities associated with the lower edge of intertidal seagrass meadows in the southern Kaipara Harbour (Morrison et al. 2014b)). Fish tend to be clumped in their distribution (occur as schools), and so beach seine tows often tend to return mostly zero catches, with the occasional catch of higher numbers. Given this, random or haphazard beach seine tows were not sufficient to capture the samples required. Rather, fish were targeted with a combination of beach seine tows, throw nets, and large dip nets, depending on local water conditions and where signs of fish were present. All sampling was undertaken about 2–3 hours each side of low tide, when fish densities are highest as fish are forced to drop into low tide pools and channels (Morrison et al. 2002). Fish 'sign' appeared as small crescent shaped swirls on the water surface, although the absence of sign did not necessarily mean the absence of fish. Most sites were too turbid to directly see the fish before capture, but at a minority of clearer water sites, fish could be seen and targeted. The key fish samplers (three people) were adept at both spotting signs of fish, and in identifying local habitat features that were more likely to hold juvenile grey mullet, e.g. the intersection of shallow intertidal channel rivulets with the main channels, sills where tidal channels shallow before joining the main channel, and structure such as tree branches. Field teams looked for these signs to target fish, as well as doing haphazard beach seine tows as they moved along the low tide channels. If insufficient fish were caught, effort continued until increasing water depth with the incoming tide made sampling impossible. Larger harbour systems had more sampling sites assigned to them, with the focus being where possible to have at least one sampling site for each major catchment area draining into the harbour. A minimum field target of ten 0+ grey mullet was set, with thirty fish as the upper limit if sufficiently common to be easily collected. On return to shore, all fish were placed in labelled plastic bags, and frozen until later processing.

## 2.3 Processing of fish, and sub-sampling for otolith processing

In the laboratory, all fish were thawed, individually measured for length, each given a unique number, and stored individually in labelled plastic bags. For each site, a random sample target of 5 individuals was subsequently selected, within a constrained size range so that all fish were 0+ individuals from the 2010 year class (larger 1+ fish were also sampled at some sites). All fish not selected were retained as archived whole fish (frozen).

## 2.4 Otolith chemistry assays

Otoliths were dissected from each fish, cleaned in ultrapure water and air-dried. An otolith from each individual was embedded in epoxy resin (Epofix, Struers) spiked with 40 ppm of indium, and then sectioned transversely through the focus (centre section) to a thickness of approximately 300 µm using a low speed diamond saw lubricated with deionized water. The sections were then polished using a 9 and 3-µm lapping film, cleaned in ultrapure water, dried overnight in a laminar flow cabinet, and mounted on glass microscope slides using indium-spiked thermo-plastic glue (Crystal Bond 509). The slides were stored in clean sealable plastic bags until analysis.

The elements used to define the grey mullet otolith chemical signature were: $^{7}$Li (Lithium), $^{23}$Na (Sodium), $^{25}$Mg (Magnesium), $^{55}$Mn (Manganese), $^{88}$Sr (Strontium), $^{138}$Ba (Barium), $^{52}$Cr (Chromium), $^{59}$Co (Cobalt), $^{65}$Cu (Copper), $^{66}$Zn (Zinc) and $^{208}$Pb (Lead). The relative concentrations of each of these elements were determined using a New Wave UP213 nm UV laser operated in Q-switch mode connected to an Agilent 7500cs inductively coupled plasma-mass spectrometer (ICP-MS). In addition, $^{43}$Ca (Calcium) was also analysed so that the element: Ca ratio could be calculated, and $^{115}$In (Indium) was analysed so that the otolith material could be distinguished from epoxy resin. Ablation of the otolith material occurred in a sealed chamber, with the ablated sample gas being extracted from the chamber and transported to the ICP-MS through a smoothing manifold in an argon and helium gas stream. The ablation chamber was purged for 20 seconds after each opening to remove any background gas or sample particles that could contaminate future samples.

A reference standard (National Institute of Standards and Technology, NIST 612) was measured after every 10 ablations to correct for instrument drift throughout each session. A calcium carbonate standard (MACS-3, United States Geological Society) was also measured at the beginning and conclusion of each session. A 30 µm spot was analysed on the outside edge of the otoliths as this represents the most recent otolith growth and corresponds to the estuary in which the fish were collected. Precision estimates for individual elements, measured as the mean relative standard deviation (RSD) were less than 5% for all elements. The concentration of each element was standardised to $^{43}$Ca. The element:Ca ratio was calculated by converting the element counts to mols, and then dividing the element in mols by Ca (mols).

## 2.5 Statistical analyses

The chemical composition of the harbour otolith sets were initially examined using multi-dimensional scaling (MDS) of the Euclidian distance matrix of log (x+0.0001) transformed element:Ca ratio data. An analysis of similarity (ANOSIM) was used to identify differences between groups. ANOSIM (Clarke 1988, 1993) is a test of the significance of the difference between groups that have been defined *a priori*. To test for significance, the ranked similarity within and between groups is compared with the similarity that would be generated by random chance. These analyses were carried out in the PRIMER software package.

Quadratic discriminant analysis (QDA) was used to classify the chemical signatures for each harbour. An investigation was then undertaken to see if the natural groupings of the sample data in the QDA vector space could be used to correctly assign otoliths to specific harbours and estuaries. Classification accuracies were determined using the leave-one-out approach (i.e., the observation being classified is removed from the data set). These analyses were carried using routines in the *MASS* library in R.

QDA is widely used for examination of otolith chemistry (e.g., Hamer et al. 2003), and has the advantage over linear discriminant analysis (LDA) in that it does not assume that measurements from each class are normally distributed.

There was potential to analyse additional archived individual fish samples, in the event that this could improve the classification accuracy markedly. The expected improvement in QDA classification accuracy as a result of increasing the number of otoliths in the QDA data set was examined by randomly selecting test data sets then using this test data set to allocate the remaining otoliths. Each simulation was repeated 1000 times with a different randomly generated test dataset.

# 3. RESULTS

## 3.1 Field collections

Between April and November 2010, over 9000 juvenile (0+) grey mullet were sampled across eight estuaries ranging from Kawhia to Herekino on the west coast and Parengarenga to Opotiki on the east coast (Figure 1). Only Little Waihi Estuary and the Otahu Estuary (both in the Bay of Plenty) returned no grey mullet, despite two and one days of extensive searching respectively. One-hundred and ninety sites within all estuaries were sampled, with 171 of these holding juvenile grey mullet.

Catch efficiencies, as a proxy of abundance, ranged from high with fish being collected very quickly, through to extensive searches being required to collect only a few fish, including covering large proportions of some of the smaller estuaries and tidal creeks. These data are being worked up elsewhere as a science paper (they fall outside this project's objectives and scope), but in brief, field observations suggested that more turbid, mud seafloor estuaries tended to hold higher abundances of juvenile grey mullet, relative to clearer water, sand seafloor estuaries. For example, on the west coast, the clear water and largely sandy Aotea Harbour held very few fish, and only one spatially limited site was found where they were present, despite extensive searching; conversely, the southern muddy inlets of the adjacent Kawhia Harbour held relatively high juvenile grey mullet abundances across multiple sites. Similarly, on the east coast the clearer water, sandy seafloor Whangateau Harbour held only low abundances, with very limited pockets of juvenile grey mullet in its upper arms; whereas the adjacent, much more turbid and muddy, Matakana Harbour held relatively high juvenile abundances.

A subsample of 573 otoliths from all of the GMU 1 harbours and estuaries was selected for chemical analysis (Table 2).

## 3.2 Individual element ratios

For the eleven elements measured, Na, Mg, and Sr returned the highest concentrations ratioed against Ca, followed by Mn, Ba, and Cu, and then lower again for Zn, Cr, Li, Co, and Pb (Appendix 1). No obvious large differences between areas or regions were immediately apparent, although the Waikato River fish returned high Li and Ba ratios.

## 3.3 Statistical analysis

### 3.3.1 Regional QDA otolith allocation tables

The MDS plot of the total estuarine data set shows one large cluster in multi-dimensional space, with some separation of groups being visually apparent (Figure 2). Pair-wise ANOSIM tests on the data show a high number of significant differences between estuaries, however, only the Waikato River data were uniquely different to all other groups (Appendix 2).

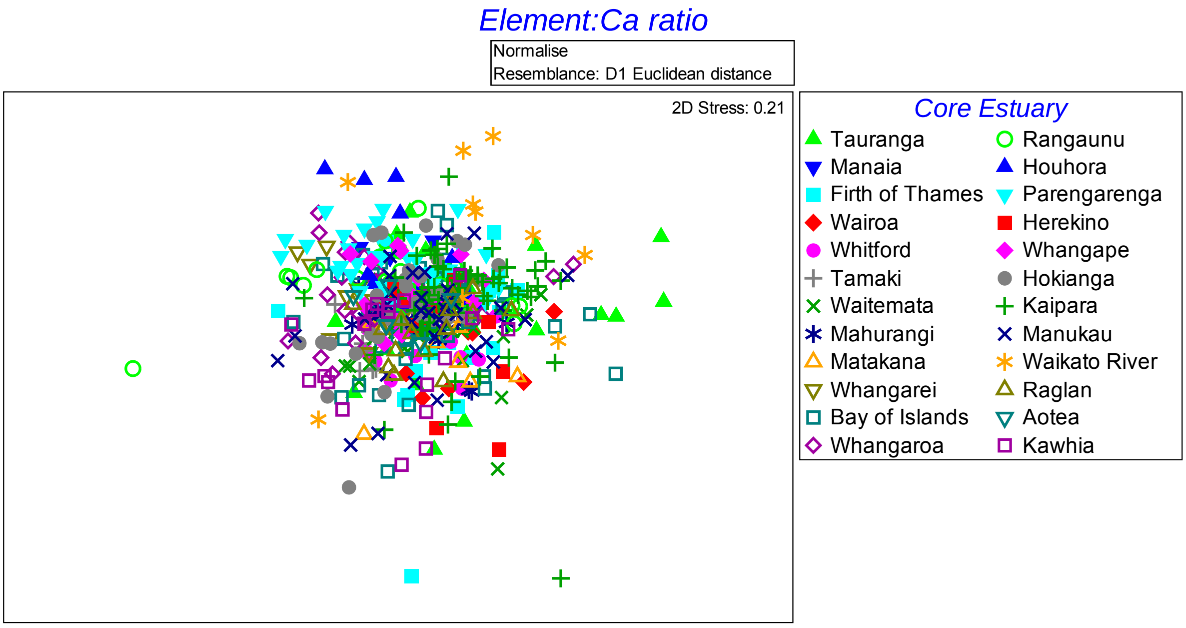


**Figure 2: Multi-dimensional scaling plot of the Euclidian distance matrix of the element: Ca ratio data from each estuary.**

A QDA requirement is to have more samples than explanatory variables in each QDA group (in this case chemical elements). To meet this requirement it was necessary to combine some of the estuary data together into larger 'key regions'. The choice of key region groupings was made with due regard to potential management scales and our understanding of the fishery (Table 3). Seven key regions were identified

**Table 3: Key-region groupings used in the GMU 1 QDA**

| Coast | Key region | Estuary | No. samples |
|---|---|---|---|
| West | SW Harbours | Kawhia | 19 |
| West | SW Harbours | Aotea | 5 |
| West | SW Harbours | Raglan | 15 |
| West | SW Harbours | Waikato River | 10 |
| West | Manukau | Manukau | 38 |
| West | Kaipara | Kaipara | 71 |
| West | NW Harbours | Hokianga | 34 |
| West | NW Harbours | Whangape | 15 |
| West | NW Harbours | Herekino | 12 |
| East | East Northland (ENLD) | Parengarenga | 35 |
| East | East Northland (ENLD) | Houhora | 9 |
| East | East Northland (ENLD) | Rangaunu | 25 |
| East | East Northland (ENLD) | Whangaroa | 30 |
| East | East Northland (ENLD) | Bay of Islands | 64 |
| East | East Northland (ENLD) | Whangarei | 20 |
| East | Hauraki Gulf (HAGU) | Matakana | 15 |
| East | Hauraki Gulf (HAGU) | Mahurangi | 15 |
| East | Hauraki Gulf (HAGU) | Waitemata | 39 |
| East | Hauraki Gulf (HAGU) | Tamaki | 10 |
| East | Hauraki Gulf (HAGU) | Whitford | 15 |
| East | Hauraki Gulf (HAGU) | Wairoa | 10 |
| East | Hauraki Gulf (HAGU) | Firth of Thames | 29 |
| East | Hauraki Gulf (HAGU) | Manaia | 9 |
| East | Bay of Plenty (BPLE) | Tauranga | 29 |

An MDS plot of these seven key regions shows a strong overlap in multi-dimensional space (Figure 3). Pair-wise ANOSIM tests on the key-region data show a high number of significant differences, however, only the Kaipara Harbour and the Bay of Plenty regions differed from all other groups (Table 4).

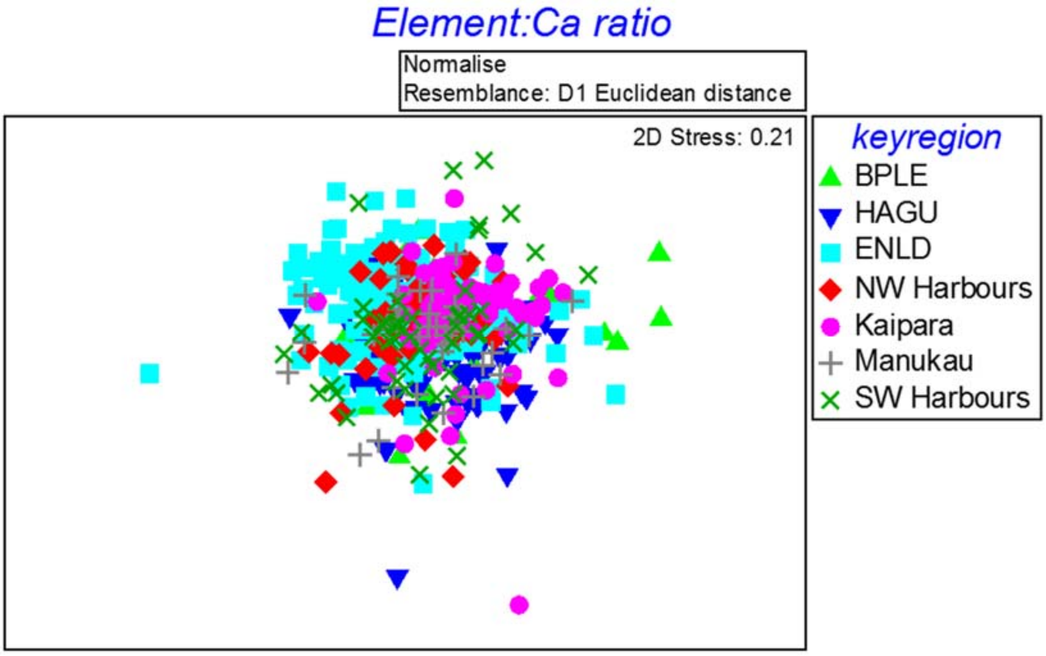


**Figure 3: MDS plot of all fish used in statistical otolith analysis, labelled by estuary groupings.**

**Table 4: Pairwise ANOSIM tests between key regions. Significant tests ($p < 0.05$) are bolded. Note that no corrections are made for Type I error, even though multiple tests are made.**

| | No. samples | SW harbours | Manukau | Kaipara | NW harbours | East Northland | Hauraki Gulf |
|---|---|---|---|---|---|---|---|
| No. samples | | 49 | 38 | 71 | 61 | 183 | 142 |
| South-west harbours | 49 | – | – | – | – | – | – |
| Manukau | 38 | 7.7 | – | – | – | – | – |
| Kaipara | 71 | **0.1** | **0.1** | – | – | – | – |
| North-west harbours | 61 | **0.1** | **3.6** | **0.1** | – | – | – |
| East Northland | 183 | **0.1** | **3.3** | **0.1** | 38.0 | – | – |
| Hauraki Gulf | 142 | **0.1** | 16.0 | **0.3** | 11.0 | **0.1** | – |
| Bay of Plenty | 29 | **4.6** | **0.1** | **0.1** | **1.1** | **0.1** | **0.1** |

The QDA confusion table (also known as a classification success table) derived from the leave one out reallocation method produced mixed results (Table 5). The overall error rate was 53% (47% accurately assigned). Correct allocation of East Northland region otoliths was high (72%). The allocation of Hauraki Gulf and Kaipara region otoliths was correct just under 50% of the time; whereas data from the remaining regions were poorly allocated, i.e., far more likely to be misallocated than allocated correctly (Table 5).

**Table 5: Predicted QDA classification at the grouped estuaries level, based on the leave-one-out approach. Table entries represent proportion of samples from each row (the true estuary group) assigned to each column Greyed cells are correct assignments.**

| **Estuary group (true)** | **Allocation success/failure (proportion)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | SW Harbours | Manukau | Kaipara | NW Harbours | ENLD | HAGU | BPLE |
| SW Harbours | 0.27 | 0.04 | 0.1 | 0.12 | 0.2 | 0.2 | 0.06 |
| Manukau | 0.03 | 0.11 | 0.16 | 0.11 | 0.18 | 0.39 | 0.03 |
| Kaipara | 0.01 | 0 | 0.46 | 0.1 | 0.15 | 0.23 | 0.04 |
| NW Harbours | 0.05 | 0.02 | 0.16 | 0.15 | 0.33 | 0.25 | 0.05 |
| ENLD | 0.02 | 0.03 | 0.05 | 0.04 | 0.72 | 0.12 | 0.02 |
| HAGU | 0.04 | 0.06 | 0.07 | 0.08 | 0.24 | 0.49 | 0.01 |
| BPLE | 0.03 | 0 | 0 | 0.28 | 0.34 | 0.1 | 0.24 |

It is useful to consider how the regional otolith sets were misclassified before drawing conclusions as to the overall discriminatory power of the method. A high degree of misclassification was evident between the east and west coast regions; for example almost half of the misclassified Kaipara Harbour otoliths (23%) were assigned to the Hauraki Gulf, while 40% of all Manukau Harbour otoliths were mis-assigned to the Hauraki Gulf (Table 5). However, the direct line distance by sea between the central and southern west coast harbours, and the Hauraki Gulf and Bay of Plenty regions of the east coast exceeds 400 nautical miles. With the assumption that substantive adult grey mullet mixing between regions greater than 400 n.mile distant is unlikely, the otolith data were divided into west and east coast regions, and separate QDAs conducted for each coast. To account for fish movement around the top of the North Island, each coastal data set also included the northern most region from the adjacent coast.

#### 3.3.1.1 West coast QDA

Key regions included in the west coast QDA were: South-west Harbours, Manukau, Kaipara, North-west Harbours, and a new region 'North-East Harbours' (comprising Parengarenga, Houhora and Rangaunu harbour data). The QDA allocation success of west coast otoliths improved for all five regions (Table 6).

**Table 6: Predicted QDA classification success for the west coast data, along with an upper east coast group of 'NE Harbours'. Greyed cells are correct assignments.**

| **Estuary group (true)** | **Allocation success/failure (proportion)** | | | | |
|---|---|---|---|---|---|
| | SW Harbours | Manukau | Kaipara | NW Harbours | NE Harbours |
| SW Harbours | 0.39 | 0.16 | 0.16 | 0.22 | 0.06 |
| Manukau | 0.05 | 0.39 | 0.24 | 0.26 | 0.05 |
| Kaipara | 0.04 | 0.07 | 0.61 | 0.18 | 0.1 |
| NW Harbours | 0.11 | 0.07 | 0.26 | 0.28 | 0.28 |
| NE Harbours | 0.04 | 0.06 | 0.07 | 0.09 | 0.74 |

#### 3.3.1.2 East coast QDA

Key regions included in the east coast QDA were: East Northland (ENLD), the Hauraki Gulf (HAGU), and the Bay of Plenty (BPLE); with the addition of a North-West Harbours (component estuaries given in Table 3).

The QDA classification achieved a moderate allocation success for the Hauraki Gulf and East Northland regions; but was relatively poor at assigning NW Harbour and Bay of Plenty otoliths (Table 7).

**Table 7: Predicted QDA classification success east coast data including region "NW Harbours". Greyed cells are correct assignments.**

| Estuary group (true) | Allocation success/failure (proportion) | | | |
|---|---|---|---|---|
| | BPLE | HAGU | ENLD | NW Harbours |
| BPLE | 0.26 | 0.08 | 0.42 | 0.24 |
| HAGU | 0.02 | 0.62 | 0.26 | 0.1 |
| ENLD | 0.04 | 0.14 | 0.74 | 0.08 |
| NW Harbours | 0.07 | 0.28 | 0.41 | 0.25 |

### 3.3.2 Effect of initial harbour otolith sample size on QDA allocation success

The analyses so far presented are based on 573 individual analysed fish otoliths, selected from across all the key estuaries sampled. Over 9000 fish were collected during the sampling, and so there is the potential to analyse additional archived fish samples.

To test whether chemical analysis of additional otoliths would be useful, the expected improvement in the overall QDA classification accuracy through increasing the otolith sample size was examined by randomly selecting test data sets of 200, 300, 400, and 500 fish from the 573 sampled fish. Error rate reduced only slightly with increasing test dataset size from 200 to 500 fish (Figure 4) therefore it does not seem likely that undertaking chemical analysis of a greater number of fish would significantly improve the classification accuracy.

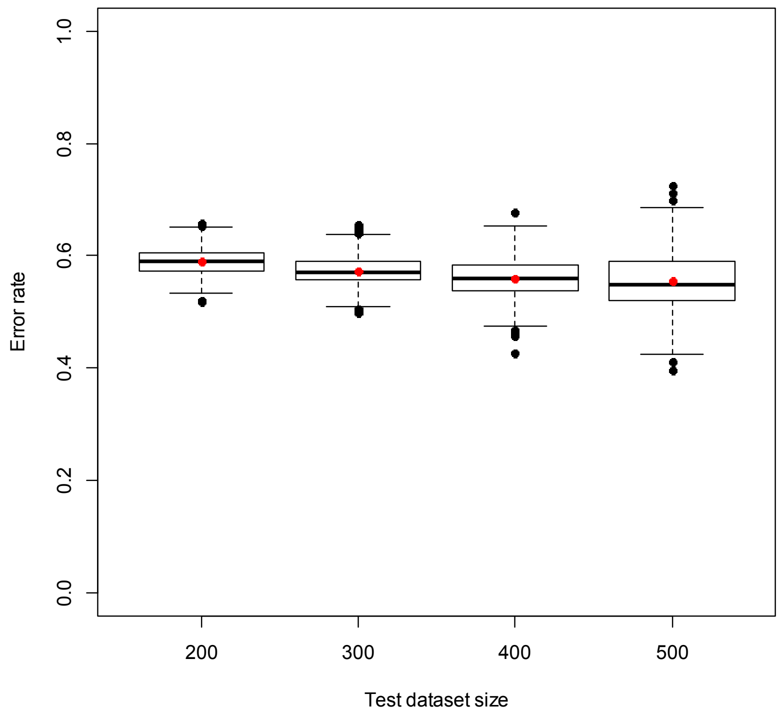


**Figure 4: Boxplots of error rate for increasing test data set sizes. Red symbols represent mean of distribution.**

### 3.3.3 Assessing the resolution power of the QDA harbour confusion tables

The proportions given in the QDA allocation tables (Table 5–7) represent the expected allocation success/failure for a pure (100%) otolith sample from each region, such that given a very large sample, the proportions observed from the QDA allocation process should closely match those given in the tables. The ideal QDA allocation table result would be to have close to 100% allocation success across all the shaded diagonal cells in Tables 5–7; however it can be seen that the real world allocation success results were relatively poor for many of the estuaries/regions. So the question now becomes: are there any estuaries/regions for which the QDA tables have 'useful' discriminatory power? To answer this question, it is necessary to consider the QDA allocation success and failure as a series of binary outcomes for each estuary/region in turn, outcomes being either an allocation to the correct estuary/region, or allocation elsewhere (i.e., all other estuaries/regions combined).

There are a range of accepted statistical procedures for assessing the classification power of the Confusion Tables exemplified in Tables 5–7. A Confusion Table's resolution power is determined by: a) the allocation success rate given that the true event status is positive, i.e., true positives (TP); and b) the misallocation rate given that the true event status is negative, i.e., false positives (FP) (*see* Appendices 3 and 4).

The QDA allocation process provides an estimate of the proportional contribution of each natal area in the otolith sample. However, due to misallocation error in the QDA process the QDA derived or what we have termed the QDA "**observed**" sample proportions are likely to be incorrect or biased. The premise of the analyses that follow is that unbiased estimates of the "**true**" natal area proportion in the sample can be derived from the QDA "observed" estimates using the formula given in Appendix 4 given that the QDA TP and FP allocation probabilities are known and $TP \neq FP$.

The QDA true positive (TP) estimates are the shaded diagonal values in Tables 5–7, while the range of possible false positive scores (FP) for each harbour system are given in the table vertical columns. So, unlike the classic binary confusion table scenario, where there is only one FP value (Appendix 3), and so there is therefore perfect linear correspondence between the "observed" (QDA) and 'true' sample proportion ratio estimates, the FP rate in the QDA tables for each harbour falls within a range defined by the smallest and largest possible FP rates. For example, when there are no true positives in the sample, the observed proportion for East Northland based on the Table 5 QDA allocation is 0.15 (smallest possible FP rate) to 0.34 (largest possible FP rate) (Figure 5). Perfect prediction, i.e. one to one correspondence between the observed proportion value and the true proportion, only occurs when the true sample proportion is 100%, i.e., the observed sample proportion can have only one value; that of the TP rate (Figure 5). The prediction uncertainty on the true proportion reduces as the true proportion ratio increases towards 100% (Figure 5).

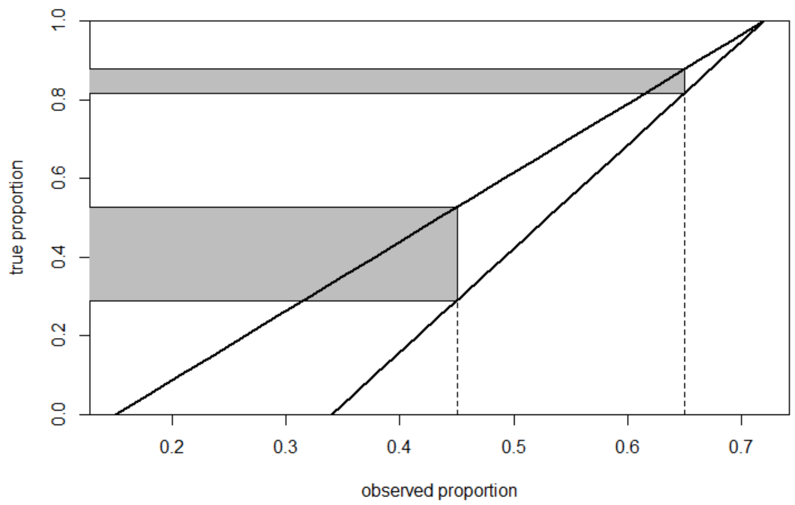


**Figure 5: 'True' sample proportion prediction range (shade bars) corresponding to east Northland Table 5 QDA allocation 'observed' proportion scores of 0.45 and 0.65.**

With the approach illustrated by Figure 5, it is possible to derive the total true proportion range associated with any observed proportion value.

Of more interest, however, is the resolution power or **Resolution Range** of the QDA allocation process for a given true proportion of otoliths in a sample. The resolution range on a given true sample proportion can be derived through projecting through the true proportion plane (Figure 6). For example the expected observed proportion range associated with a true East Northland (Table 5) QDA allocation of 0.8 is 0.61 to 0.66 (Figure 6a). However in the instance where the actual observed ratio was 0.61, the prediction range on the 'True' proportion estimate would be 0.70 to 0.80 (Figure 6a). Likewise, the prediction range on an observed ratio of 0.66 is 0.8 to 0.87 (Figure 6a). Therefore the east Northland QDA Resolution Range for a given true sample proportion of 0.8 is 0.70 to 0.87 (Figure 6a). The predictive power of the QDA when the true level is 0.80 is sufficiently tight so as to lead to a 'strong' interpretation, i.e., there is a high (> 70%) predominance of east Northland fish in the sample.

It can be seen from Figure 6 that as the true proportion of East Northland fish in the sample gets smaller, the associated resolution range increases. The resolution range for a true proportion of 0.2 for example is 0.0 to 0.47 (Figure 6b), i.e., the 'strongest' interpretation, given a true value of 0.2, being that the sample likely contains less than 50% east Northland fish.

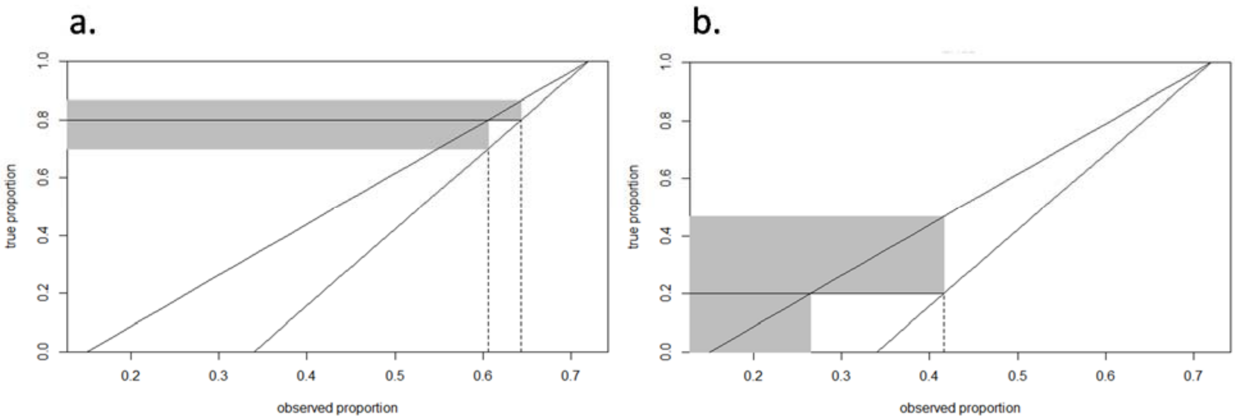


**Figure 6: East Northland Table 5 QDA true-proportion Resolution Ranges corresponding to 'true' sample proportions of: a) 0.8 [observable proportion range: 0.61 ~ 0.66 (vertical dotted lines); 'true' resolution range: 0.70 ~ 0.87 (shaded horizontal bars)]; b) 0.2 [observable proportion range: 0.26 ~ 0.42 (vertical dotted lines); 'true' resolution range: 0.0 ~ 0.47 (shaded horizontal bars)].**

For most of the grey mullet key estuaries/regions, the QDA resolution power was ‘very strong’ at sample proportions close to 1.0 (resolution range 0 ~ 0.1) but as the true sample proportion decreases, the value at which the associated QDA resolution range score could be classed as having ‘weak’ interpretative power becomes increasingly subjective. We found it necessary to develop our own five-level QDA maximum resolution strength classification (Table 8). Based on our classifications (Table 8), the East Northland QDA allocation Table 5 has ‘strong’ resolution power for a true east Northland sample proportion of 0.8, and ‘weak’ resolution power at 0.2.

**Table 8: Interpretative utility of true-proportion maximum resolution range scores.**

| Resolution range | Resolution strength |
|---|---|
| 0 ~ 0.1 | very strong |
| 0.1 ~ 0.2 | strong |
| 0.2 ~ 0.3 | moderate |
| 0.3 ~ 0.5 | weak |
| > 0.5 | none |

### 3.3.4 Assessing QDA GMU 1 sample discriminatory power (resolution ranges) under finite sampling scenarios

**Methods**

The East Northland resolution range values corresponding to true proportions of 0.8 and 0.2 given in Figure 6 make no allowance for sampling variation. Under finite sampling, variability in the QDA observed proportion ratio which is used to derive the true proportion resolution range is likely to come from:

a. Variation in the actual true ratio in the harbour sample in relation to sample size.
b. Inherent variability in the QDA allocation process, i.e., the TP and FP QDA table allocation values.

We used bootstrap resampling methods (described in Appendix 5) to derive true proportion resolution range estimates for the three area QDAs (Tables 5–7) that incorporated finite sampling error. Bootstraps were performed covering a true sample proportion range for each natal region from 0 to 1.0 in 0.01 increments.

**Results**

The bootstrap resolution ranges from the GMU 1 QDA (Table 5) allocation process fall within the ‘weak’ or ‘none’ range (i.e., resolution range over 0.3) for most estuaries/regions and true sample proportions (Figure 7, Appendix 6). The GMU 1 QDA is likely only to have ‘moderate’ (0.2–0.3) resolving power in cases where a 500 fish otolith sample contains 90% or more East Northland (ENLD) origin grey mullet (Figure 8, Appendix 6). Strong biases are evident in the bootstrap resolution ranges for Bay of Plenty (BPLE) and Kaipara Harbour regions as indicted by the range medians (Figure 7). These biases came about because the QDA TP values given in Table 5 (diagonal values) were well to the right of TP QDA bootstrap mode (Figure 9).

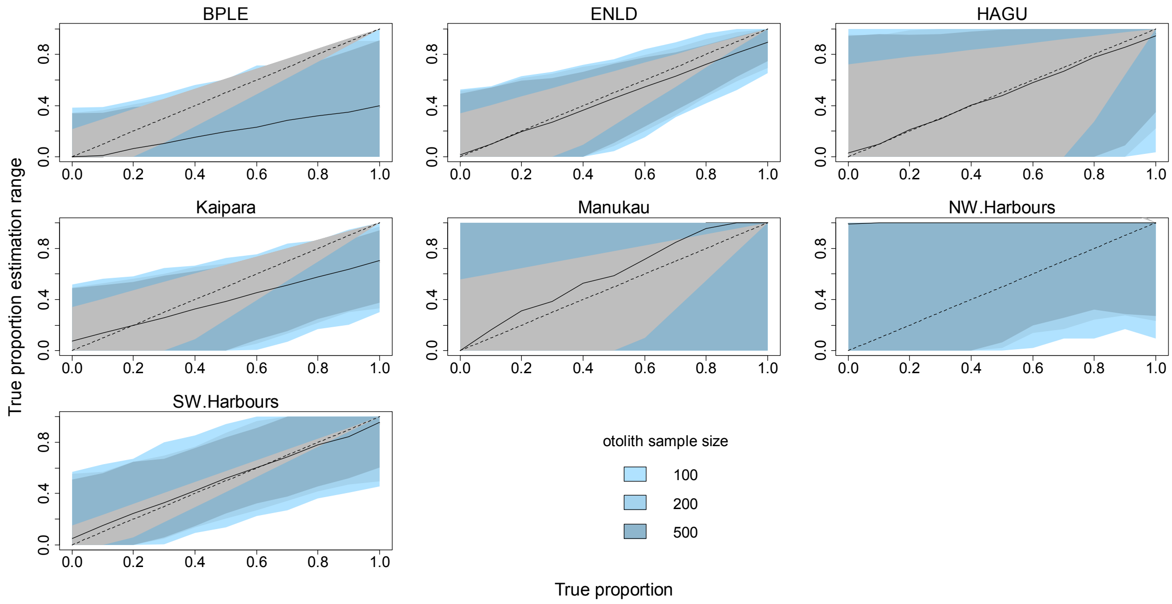


**Figure 7: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range. Grey shaded area represents the 'idealised' resolution range according to the TP and maximum and minimum FP allocation proportions from Table 5. Solid lines are the bootstrap 'true' predicted value medians (500 otolith samples).**

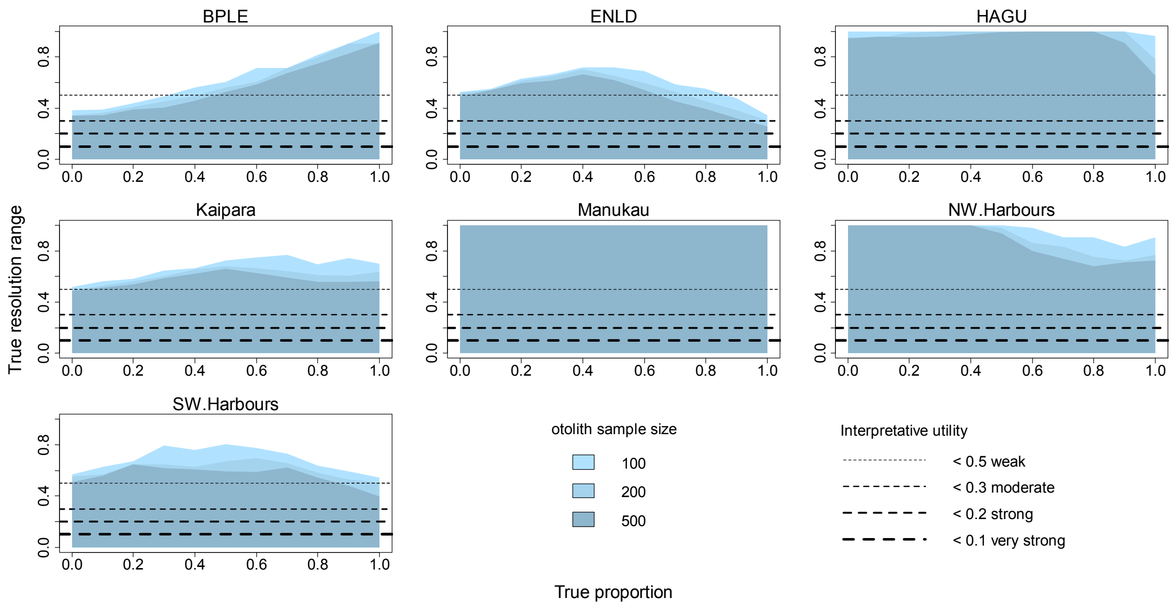


**Figure 8: All GMU 1 region QDA (Table 5) 95% bootstrap resolution range by true sample proportion. Dotted lines indicate arbitrary levels of resolving power in the QDA. We deem the QDA to have 'moderate' predictive utility for a given true proportion when the corresponding bootstrap resolution range is less than 0.3.**

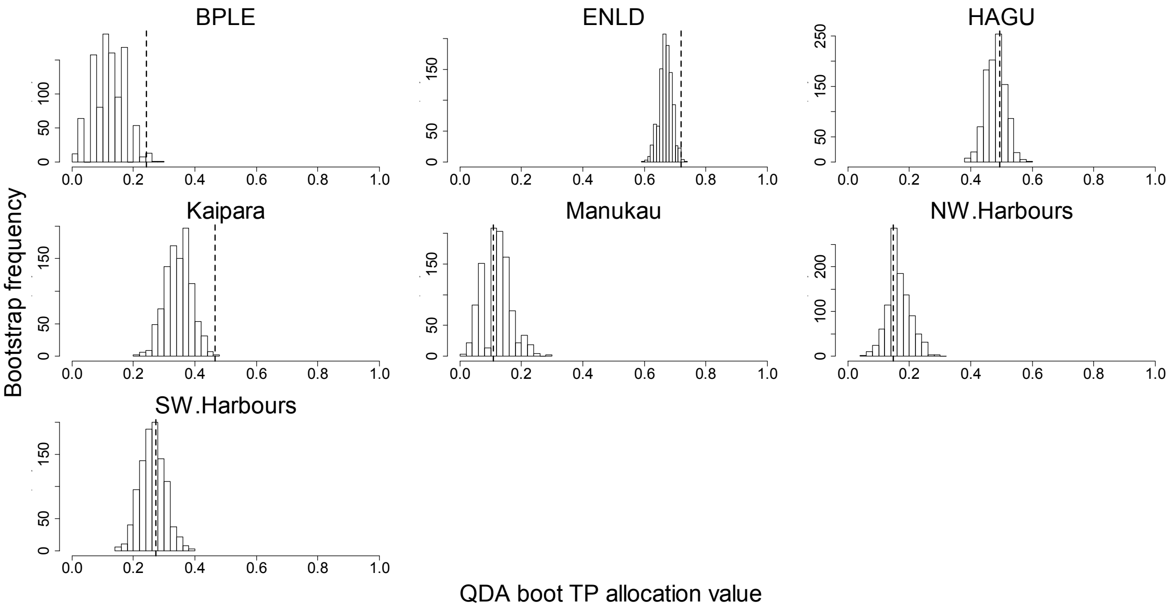


**Figure 9: Frequency histograms of QDA bootstrap true proportion (TP) estimates for each GMU 1 region. Dotted vertical lines denote the regional QDA TP values (i.e., diagonal values from Table 5).**

The bootstrap resolution ranges from the west coast QDA (Table 6) allocation process fall within the 'weak' or 'none' range (i.e. over 0.3) for most harbour regions and true sample proportions (Figure 10, Appendix 7). QDA resolving power for the three northern-most East Northland harbours (NE Harbours) was 'moderate' (0.2–0.3) in cases where a 500 otolith sample contained 90% or more NE Harbours origin grey mullet (Figure 11, Appendix 7). Biases are evident in the bootstrap resolution ranges for the Manukau and Kaipara harbour regions as indicted by the range medians (Figure 10); as above the explanation is due to bias in the QDA bootstrap TP estimates (Figure 12).

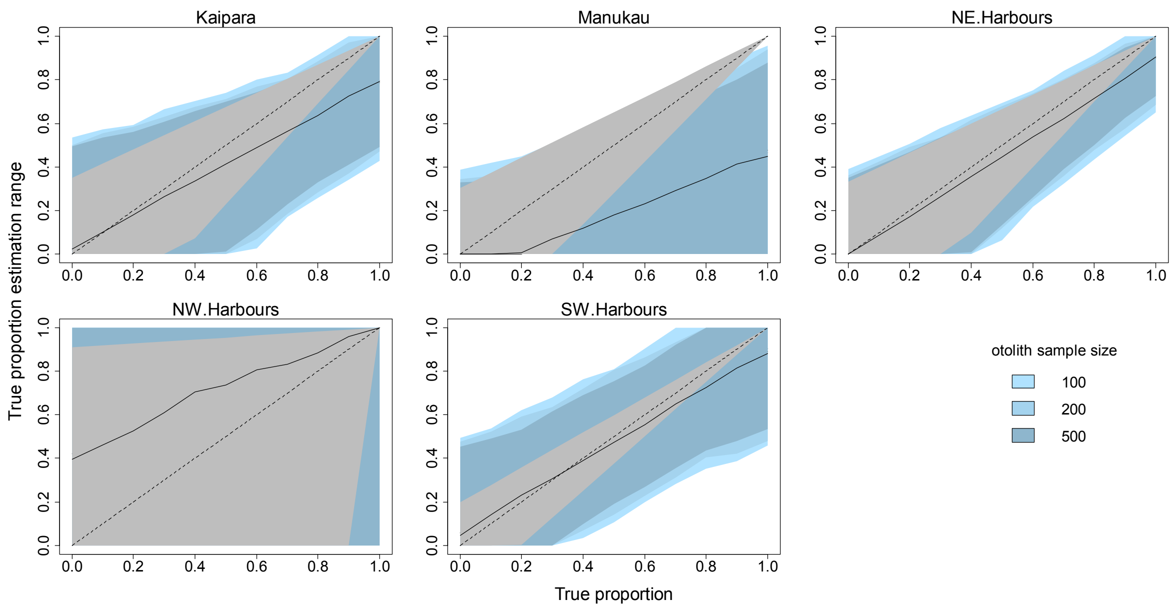


**Figure 10: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range. Grey shaded area represents the 'idealised' resolution range according to the TP and maximum and minimum FP allocation proportions from Table 6. Solid lines are the bootstrap 'true' predicted value medians (500 otolith samples).**

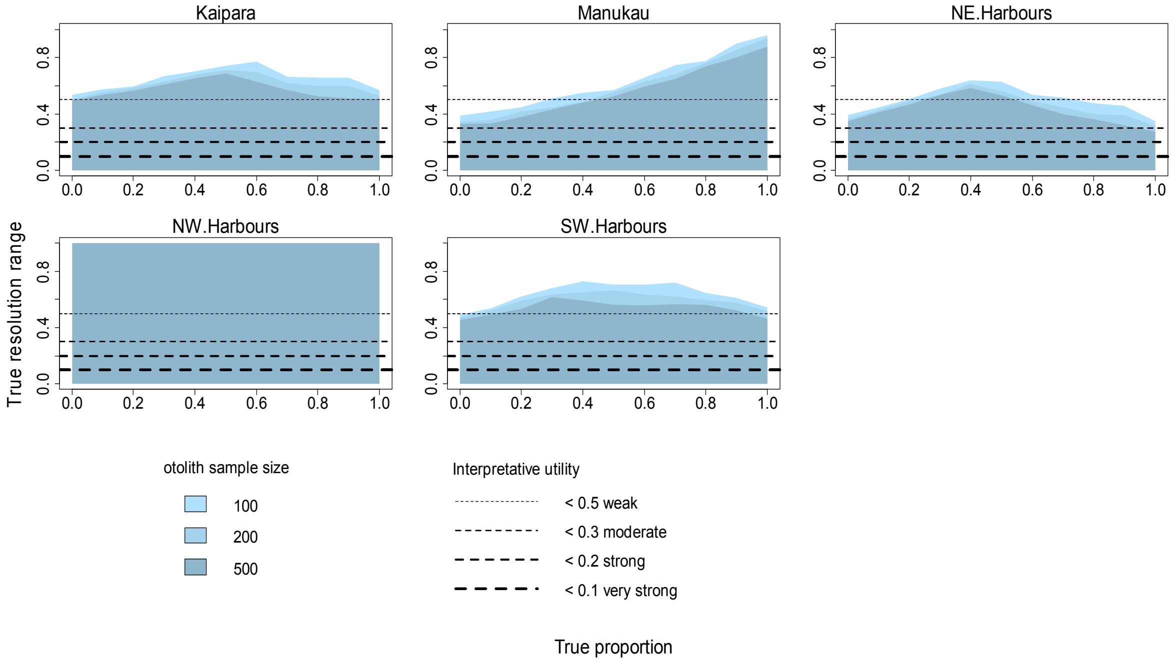


**Figure 11: West coast region QDA (Table 6) 95% bootstrap resolution range by true sample proportion. Dotted lines indicate arbitrary levels of resolving power in the QDA. We deem the QDA to have 'moderate' predictive utility for a given true proportion when the corresponding bootstrap resolution ranges are less than 0.3.**

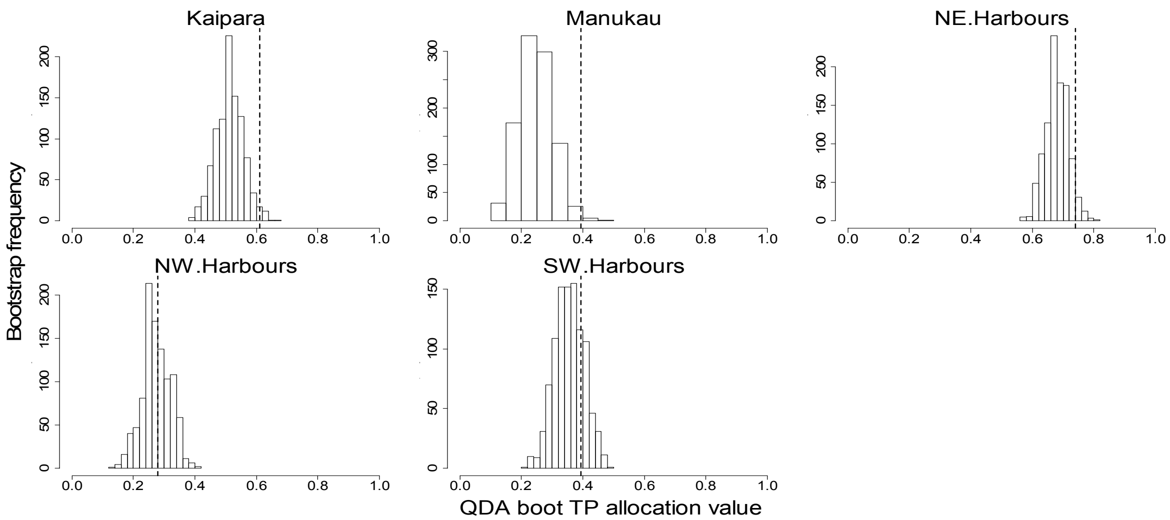


**Figure 12: Frequency histograms of QDA bootstrap true proportion (TP) estimates for each west coast region. Dotted vertical lines denote the regional QDA TP values (i.e. diagonal values from Table 6).**

The bootstrap resolution ranges from the east coast QDA (Table 7) allocation process fall within the 'weak' or 'none' range (i.e. over 0.3) for most regions and true sample proportions (Figure 10, Appendix 7). QDA resolving power for east Northland (ENLD) and the Hauraki Gulf (HAGU) and was 'moderate' (0.2–0.3) in cases where a 500-otolith sample contained 90% or more grey mullet from these regions (Figure 13, Appendix 8). The QDA also has 'moderate' resolving power to determine if a 500-otolith sample comprises less than 0.10 of Bay of Plenty origin grey mullet. Biases are evident in the bootstrap resolution ranges for the Bay of Plenty (Figure 13, Figure 15, Appendix 8), but this is unlikely to affect the QDA's 'low sample proportion' resolving power for this region.

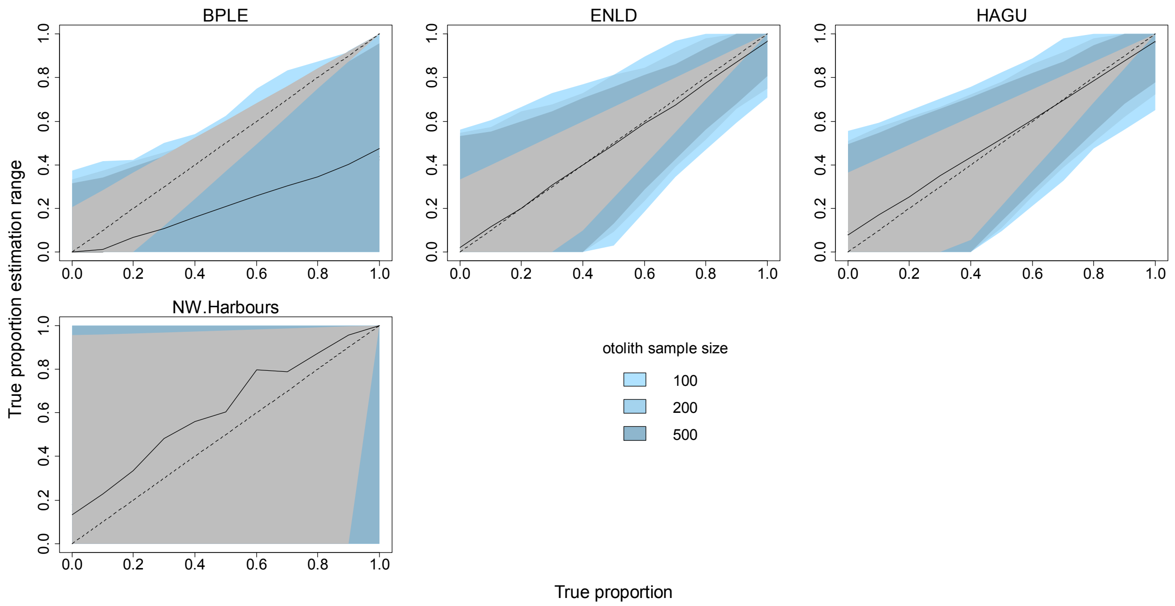


**Figure 13: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range. Grey shaded area represents the 'idealised' resolution range according to the TP and maximum and minimum FP allocation proportions from Table 7. Solid lines are the bootstrap 'true' predicted value medians (500 otolith samples).**

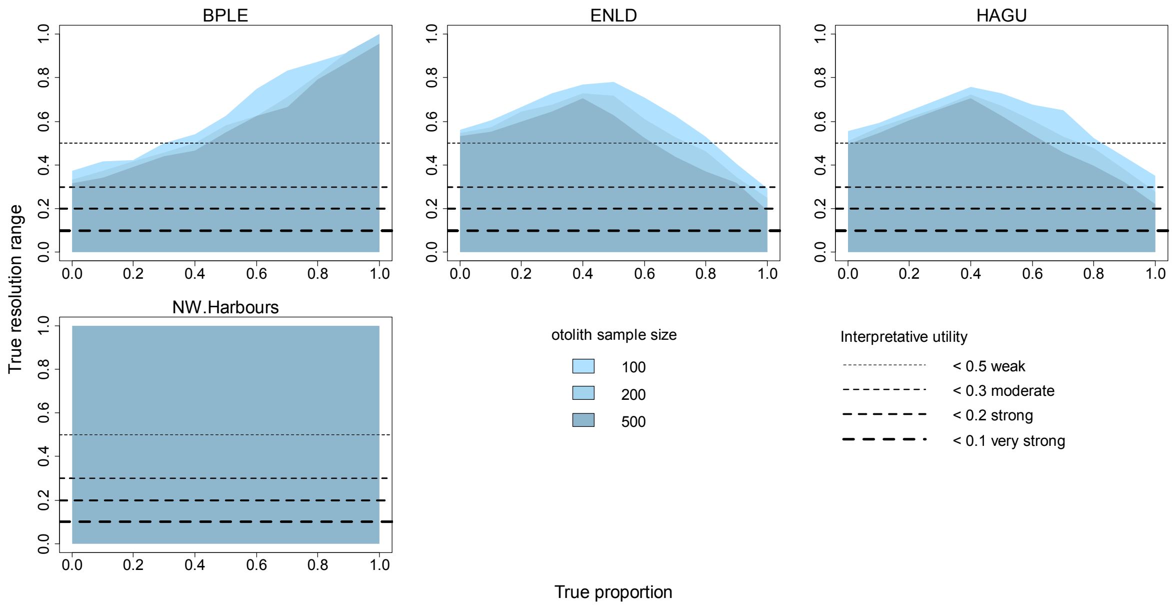


**Figure 14: East coast region QDA (Table 7) 95% bootstrap resolution range by true sample proportion. Dotted lines indicate arbitrary levels of resolving power in the QDA. We deem the QDA to have 'moderate' predictive utility for a given true proportion when the corresponding bootstrap resolution ranges are less than 0.3.**

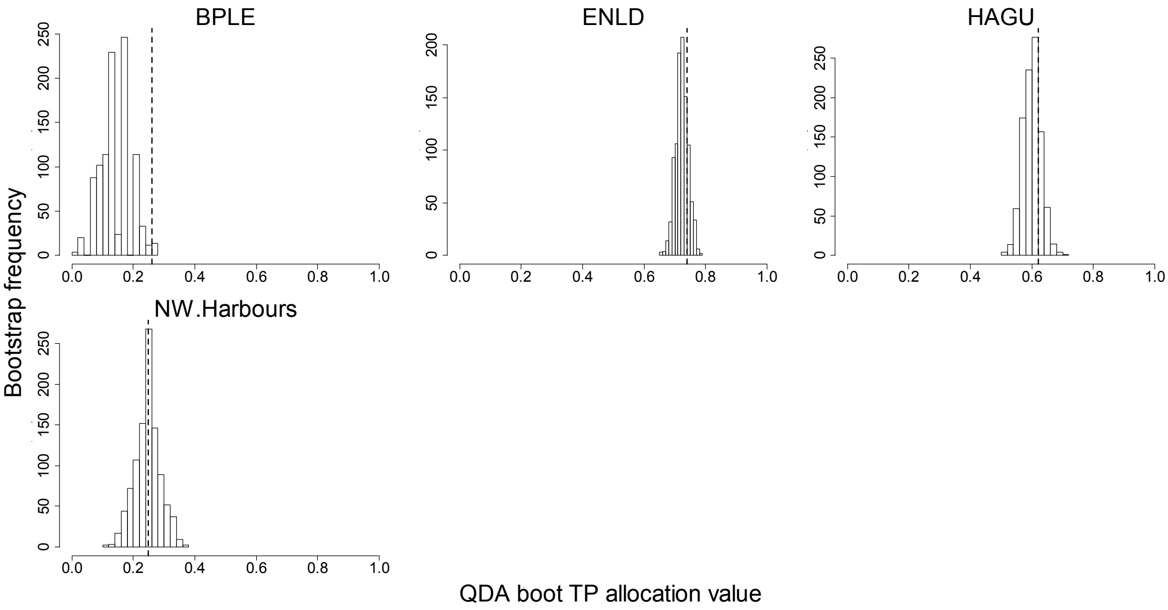


**Figure 15: Frequency histograms of QDA bootstrap true proportion (TP) estimates for each east coast region. Dotted vertical lines denote the regional QDA TP values (i.e., diagonal values from Table 7).**

### 3.3.5 95% CI range on the "True" sample proportion estimate for a given QDA "observed" proportion

In a real-world application of the QDA allocation process only the "observed" (QDA derived) proportion is known. Therefore, in application we are likely to be more interested in knowing the 95% CI range on the predicted "true" sample proportion associated with a given QDA derived or "Observed" proportion. Under the bootstrap process described in Section 3.3.4 above, 1000 random "Observed" ratios are generated for each 0.01 true proportional increment between 0.0 and 1.0 for each natal region, i.e. a uniform number of observed values across the entire range of true values. These bootstrap results as well as providing the distribution of Observed values for each given true value also provide an unbiased estimate of the distribution of true proportions relative to a given "observed" value (*see* Appendix 9).

Confidence intervals on the "true" expected proportion as derived from a given QDA "observed" value based on a 500 otolith sample are given in Appendices 10, 11 and 12.

## 4. DISCUSSION

During the 2010 year, over 9000 juvenile (0+) grey mullet were collected from harbours, estuaries and embayment's across GMU 1. Otolith chemistry analyses were undertaken on 573 otoliths subsampled from the wider collection. The otolith chemistry data were divided into seven GMU 1 regions: South West Harbours, Manukau Harbour, Kaipara Harbour, East Northland, Hauraki Gulf and the Bay of Plenty. Quadratic discriminant analyses (QDA) were undertaken on the otolith data to develop a tool for allocating otoliths of unknown origin to their juvenile region.

The allocation power of the QDA to assign grey mullet otoliths to their GMU 1 juvenile regional origin is determined by a) the probability of correctly assigning a fish to a given juvenile region (true positive, TP), and b) the probability of incorrectly assigning fish from other GMU 1 regions to that region (false positive, FP). The QDA allocation process provided estimates of true and false positive probabilities for each GMU 1 natal region. Using the TP and FP QDA allocation probabilities for a given GMU 1 region, it was possible to determine what proportion of the otoliths from a given sample came from that region as an upper and lower range; we term this the Resolution Range of the QDA. We believe the QDA allocation process could have utility in assigning GMU 1 grey mullet to natal regions when the Resolution Range for a given regional sample is less than 0.3.

The QDA success at assigning otoliths to any one of seven natal regions across 'all GMU 1' was relatively 'poor' for all regions except East Northland. The bootstrap simulation results indicate that the GMU 1 wide QDA is likely to have utility for estimating the composition ratio of East Northland origin grey mullet when the true proportional composition in a 500 otolith sample is greater than 0.90, the conclusion being that true sample portion is within the range 0.7–1.0.

Accepting the hypothesis that adult grey mullet from the extreme east and west coast GMU 1 regions are unlikely to mix (i.e., there are at least two separate GMU 1 stocks) allowed for two separate QDA spatial analyses on the available otolith data. Otoliths from the three northernmost East Northland harbours (Parengarenga, Houhora, and Rangaunu) were included in the 'west coast QDA'. Likewise otoliths from the top three west coast harbours (Hokianga, Whangape, and Herekino) were included in the 'east coast QDA'. East Northland harbours again featured as having high resolving power at true sample ratios of 0.9 in both east and west coast QDAs. The west coast QDA resolving power in identifying otoliths from the four other west coast regions, included the Kaipara and Manukau harbours, was poor. In addition to East Northland, the east coast QDA had comparable resolving power for Hauraki Gulf origin otoliths at true sample proportion levels of 0.90 or higher.

Unfortunately it is not possible to determine *a priori* how 'useful' an adult GMU 1 sampling programme would be for furthering our understanding of grey mullet stock structure. Our results indicate that for the ‘all GMU 1 QDA’, there is utility to determine from a 500 otolith sample taken anywhere within ‘all GMU 1’ whether it comprised 0.9 or higher proportion of east Northland origin fish. Given a 500 grey mullet otolith sample, the ‘east coast QDA’ has the power to identify East Northland and Hauraki Gulf natal origin grey mullet at sample compositional levels greater than 0.9. We believe a high contribution result for either of these regions would have strong management implications. For example, a high Hauraki Gulf juvenile signal in recruited Hauraki Gulf grey mullet would suggest that Hauraki Gulf grey mullet are a closed population. There are similarly important management implications if other east coast GMU 1 regions produced high Hauraki Gulf natal origin signals.

Our simulations indicated that only minor improvement in the QDA allocation success would be achieved through the inclusion of more data (more individual fish). However, given that nearly 9000 juvenile grey mullet samples were collected, there may be utility in processing additional otoliths of known origin for additional elements and/or isotopes if possible, such as arsenic, which is known to occur at high natural concentrations in regions with high past volcanic activity, such as the Bay of Islands. Such additions might further improve the QDA allocation power.

## 5. CONCLUSIONS

Although the 2010 natal otolith datasets and QDA analytical procedures provide some power to identify relatively pure samples of adult east Northland 2010 natal origin grey mullet collected anywhere within GMU 1 overall, the ability of these data to assign adult grey mullet to their natal region using otolith chemistry was ‘poor’, with insufficient precision to be considered useful for exploring the stock relationships of grey mullet. The conclusion of this report, and of the Northern Inshore Finfish Working Group, is that sampling of adult mullet to match otolith chemistries with the juveniles, for large scale stock discrimination, is not recommended.

The potential remains for useful work at finer spatial scales, although outside the scale focus of the GMU200901 project reported on here. There were many individual estuaries that differed significantly from each other in their chemistries within geographic segments of coast; additionally, a range of smaller estuaries sampled had chemistries not used in the current analyses. Some estuaries were also more exhaustively sampled, to provide a potential baseline for looking at source-sink dynamics at the individual estuary scale (e.g. what proportion of fish in an estuary were locally recruited (sourced)). Examples include Whangaroa Estuary (East Northland) Whangateau Estuary (northern Hauraki Gulf), Whangapoua Estuary (East Coromandel), Kaipara Harbour (west coast), and some offshore islands (e.g. Great Barrier Island, outer Hauraki Gulf). These data remain to be explored. We note that if there are significant inter-annual variations in chemistry, the ability to sample and match up adult chemistries from the 2010 year class has a limited time window. As juveniles were sampled in 2010, the adults from that year class will now be 6+ fish, and fully recruited to the fisheries. While recent work on New Zealand grey mullet indicates that they may live to 19+ years or more in some unfished sub-populations (Morrison et al., unpubl. data), most will not survive beyond 8 to 9 years given heavy fishing pressures. This limits the time remaining to sample the 2010 year class as adults, to the next 2–3 years.

In addition, a significant adult grey mullet biomass exists in freshwater populations (lakes and rivers) whose recruitment origins and linkages to marine populations remain ambiguous. The few juveniles collected in the lower Waikato River had chemistries which differed from all other juvenile locations, suggesting that identifying freshwater nursery derived adult fish should be relatively easy (assuming that such nurseries exist). Ongoing work on the otolith chemistry of adult fish (as collected and analysed through the MBIE CCM programme), combined with some of the data reported on here, will help address these (and other) questions.

## 6. ACKNOWLEDGEMENTS

We thank MPI for funding this work under project GMU200901, and MBIE through programme 'Coastal Conservation Management' (CO1X0907) for the additional resources to extend out the nature of the programme to encompass a broader geographical reason, and to target some additional ecological questions. Many people spent a lot of time in estuary mud chasing down the samples; particular thanks go to Crispin Middleton, Marie Jamieson, Cameron Walsh, and Dane Buckthought, as well as Marie Jordan, Catriona Paterson, Emma Jones, Meredith Lowe, Darren Parsons, Brandon Morrison, Cosmos Hetherington, Kayla Gilmore and Laura Falkenberg.

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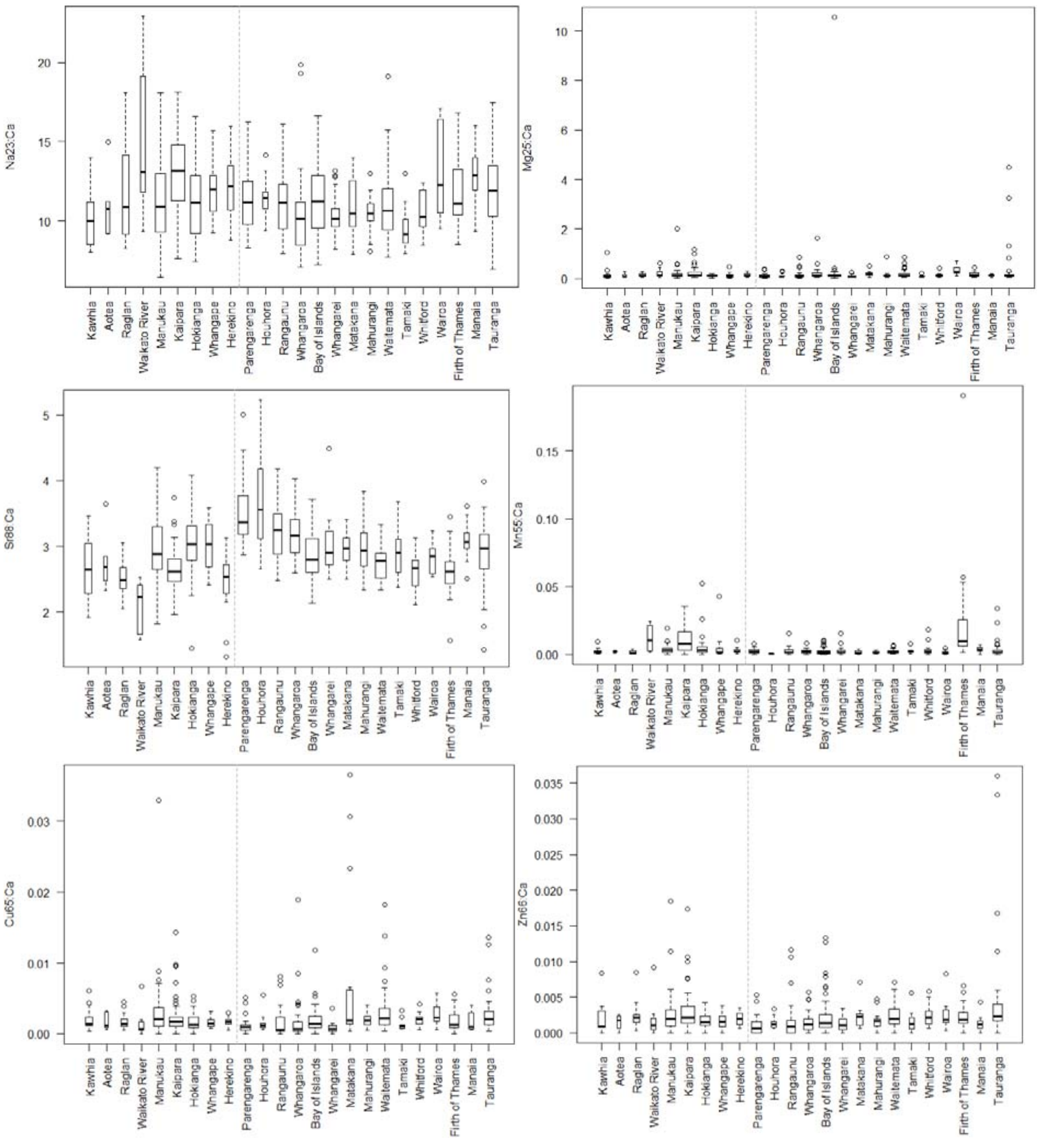
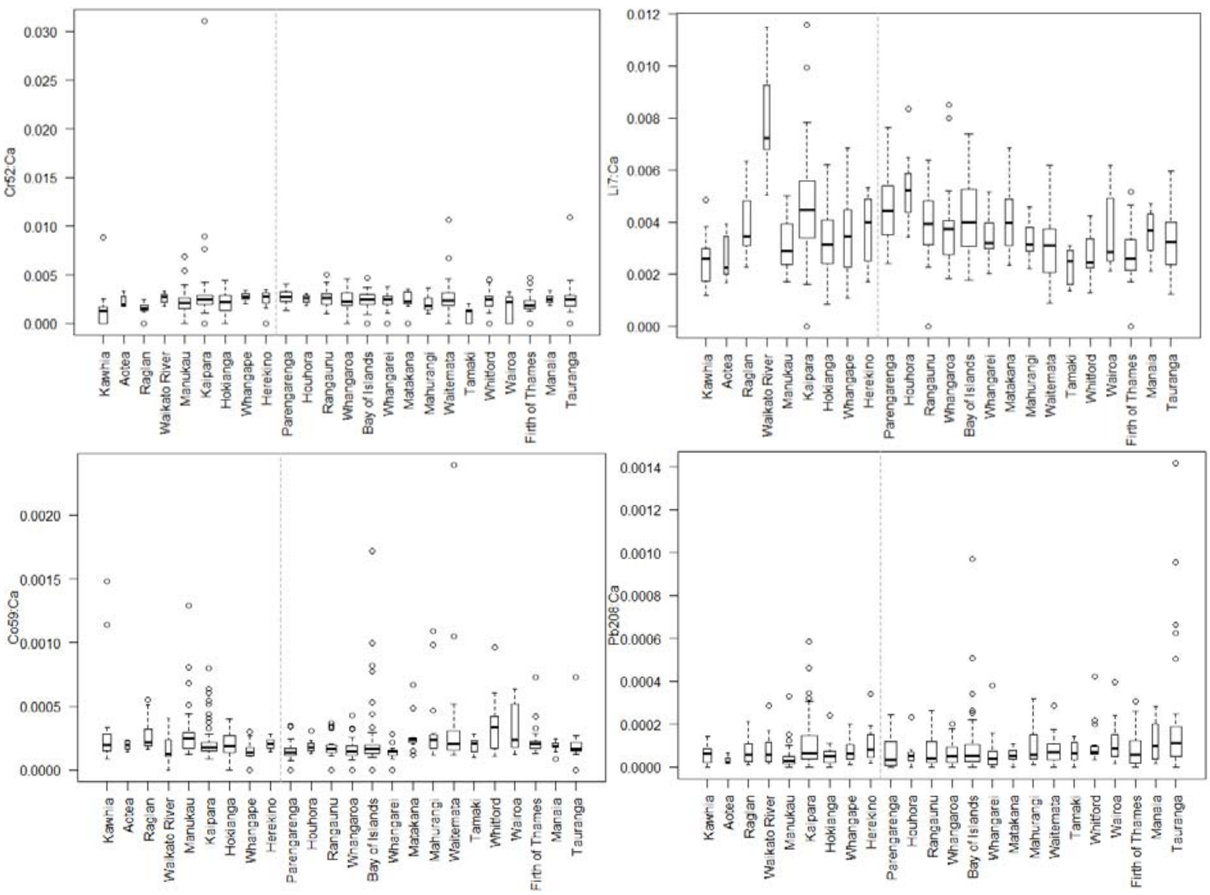
## 8. APPENDICES

**Appendix 1: Univariate box plots of element to Ca ratios for the eleven elements measured, ordered by decreasing maximum ratios. The dotted vertical line splits the west and east coast regions.**




Cr52:Ca
Li7:Ca
Co59:Ca
Pb208:Ca
Kawhia
Aotea
Raglan
Waikato River
Manukau
Kaipara
Hokianga
Whangape
Herekino
Parengarenga
Houhora
Rangaunu
Whangaroa
Bay of Islands
Whangarei
Matakana
Mahurangi
Waitemata
Tamaki
Whitford
Wairoa
Firth of Thames
Manaia
Tauranga

**Appendix 2: Pairwise ANOSIM tests between all estuaries. Significant tests ($p < 0.05$) are shaded. Note that no corrections are made for Type I error, to allow for the large numbers of tests made**

| | No. samples | Kawhia | Aotea | Raglan | Waikato River | Manukau | Kaipara | Hokianga | Whangape | Herekino | Parengarenga | Houhora | Rangaunu | Whangaroa | Bay of Islands | Matakana | Whangarei | Mahurangi | Waitemata | Tamaki | Whitford | Wairoa | Firth of Thames | Manaia |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. samples | | 19 | 5 | 15 | 10 | 38 | 71 | 34 | 15 | 12 | 35 | 9 | 25 | 30 | 64 | 20 | 15 | 15 | 39 | 10 | 15 | 10 | 29 | 9 |
| Kawhia | 19 | | | | | | | | | | | | | | | | | | | | | | | |
| Aotea | 5 | 90.9 | | | | | | | | | | | | | | | | | | | | | | |
| Raglan | 15 | 0.5 | 11.4 | | | | | | | | | | | | | | | | | | | | | |
| Waikato River | 10 | 0.1 | 0.2 | 0.1 | | | | | | | | | | | | | | | | | | | | |
| Manukau | 38 | 1.5 | 83.8 | 40 | 0.1 | | | | | | | | | | | | | | | | | | | |
| Kaipara | 71 | 0.1 | 25.5 | 9.5 | 0.1 | 0.1 | | | | | | | | | | | | | | | | | | |
| Hokianga | 34 | 1.2 | 78.1 | 3.6 | 0.1 | 13.2 | 0.3 | | | | | | | | | | | | | | | | | |
| Whangape | 15 | 1.3 | 43.8 | 0.1 | 0.1 | 42.2 | 18.6 | 71.4 | | | | | | | | | | | | | | | | |
| Herekino | 12 | 4.4 | 48.2 | 17.8 | 0.1 | 38.9 | 31 | 23.4 | 1.2 | | | | | | | | | | | | | | | |
| Parengarenga | 35 | 0.1 | 17.8 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 7 | 0.1 | | | | | | | | | | | | | | |
| Houhora | 9 | 0.2 | 0.9 | 0.1 | 0.1 | 1.2 | 0.1 | 2.9 | 0.5 | 0.1 | 0.7 | | | | | | | | | | | | | |
| Rangaunu | 25 | 0.1 | 72.9 | 0.8 | 0.1 | 1.9 | 0.1 | 6 | 63.2 | 17.5 | 12.9 | 11 | | | | | | | | | | | | |
| Whangaroa | 30 | 0.4 | 77.9 | 5.2 | 0.1 | 0.2 | 0.1 | 0.2 | 13.1 | 10.9 | 0.1 | 0.4 | 29.3 | | | | | | | | | | | |
| Bay of Islands | 64 | 0.1 | 67.6 | 73 | 0.1 | 0.7 | 0.1 | 3.5 | 29 | 52.1 | 0.1 | 1.5 | 6.9 | 6.5 | | | | | | | | | | |
| Matakana | 20 | 0.3 | 17.4 | 1.4 | 0.1 | 72.8 | 8.9 | 19.3 | 0.1 | 3.8 | 0.1 | 0.1 | 10.7 | 16.6 | 71.3 | | | | | | | | | |
| Whangarei | 15 | 0.1 | 50.7 | 0.1 | 0.1 | 12.5 | 0.6 | 26 | 1.6 | 3.8 | 3.4 | 0.2 | 46.4 | 88.1 | 63.4 | 0.1 | | | | | | | | |
| Mahurangi | 15 | 0.7 | 28.7 | 2.1 | 0.1 | 72.1 | 2.3 | 30.7 | 0.1 | 2.7 | 0.1 | 0.1 | 14.3 | 44.4 | 81.5 | 0.5 | 3.5 | | | | | | | |
| Waitemata | 39 | 0.2 | 70.1 | 39.6 | 0.1 | 4.6 | 0.1 | 0.1 | 5.4 | 34.6 | 0.1 | 0.2 | 0.1 | 0.1 | 8.4 | 0.4 | 70.5 | 65.9 | | | | | | |
| Tamaki | 10 | 99.8 | 20.7 | 0.2 | 0.1 | 38.4 | 0.4 | 38.8 | 0.1 | 0.2 | 0.1 | 0.1 | 7.4 | 32 | 13.7 | 1.1 | 0.1 | 0.5 | 6.5 | | | | | |
| Whitford | 15 | 24.6 | 52.4 | 1 | 0.1 | 51.9 | 3.2 | 15 | 0.2 | 13.8 | 0.1 | 0.1 | 0.4 | 1.6 | 13.8 | 0.1 | 0.1 | 1.5 | 34.4 | 2.7 | | | | |
| Wairoa | 10 | 7 | 26.5 | 1.4 | 0.1 | 16.2 | 1.6 | 3.7 | 0.1 | 5.8 | 0.1 | 0.1 | 2.6 | 3.4 | 6.2 | 0.1 | 1.8 | 0.5 | 4.7 | 0.3 | 3.4 | | | |
| Firth of Thames | 29 | 0.1 | 36.2 | 0.5 | 0.1 | 0.5 | 5.5 | 0.1 | 0.2 | 12.6 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 1.3 | 0.1 | 4.2 | 3.4 | 0.6 | | |
| Manaia | 9 | 13.5 | 43.3 | 0.4 | 0.1 | 49.6 | 29.9 | 62.5 | 38.7 | 28.8 | 20 | 0.3 | 82.6 | 52.1 | 53.9 | 13.4 | 4 | 3.2 | 18.5 | 0.1 | 0.8 | 3.2 | 13.7 | |
| Tauranga | 29 | 4.2 | 86.3 | 3.3 | 0.2 | 0.1 | 0.1 | 0.3 | 96.7 | 55.7 | 0.1 | 25.6 | 0.2 | 0.1 | 0.1 | 2 | 12.7 | 11.5 | 0.1 | 35.1 | 56.1 | 29.2 | 0.1 | 79.2 |

**Appendix 3: Confusion table general concepts**

The success of failure of a process to successfully predict a ‘true’ outcome can be represented as a 2×2 matrix (Appendix Figure 1):

| | | prediction outcome | | |
|---|---|---|---|---|
| | | ***p*** | ***n*** | **total** |
| **actual value** | ***p'*** | True Positive | False Negative | P' |
| | ***n'*** | False Positive | True Negative | N' |
| | **total** | P | N | |

**Appendix Figure 1: General form of the 2×2 binary confusion matrix.**

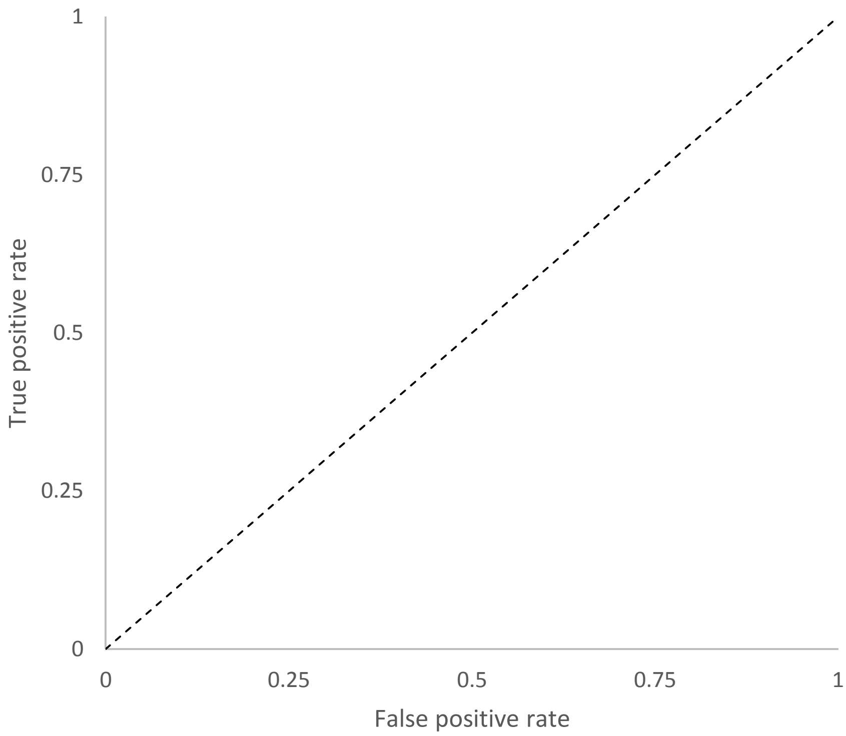
From Appendix Figure 1 the probability of the allocation process resulting in a ‘true positive’ (TP) is

$$p[TP]= \frac{TP}{P'}$$

Likewise the probability of a ‘false positive’ (FP) is

$$p[FP]= \frac{FP}{N'}$$

Receiver operating characteristics (ROC) graphs are commonly used to assess the discriminatory power of a binary allocation process (Fawcett 2006). ROC graphs are two-dimensional graphs in which TP rate is plotted on the Y axis and FP rate is plotted on the X axis (Appendix Figure 2). A binary classifier that never produces a positive result corresponds to the lower left point (0, 0) and represents the strategy of never issuing a positive classification; such a classifier commits no false positive errors but also gains no true positives. The opposite strategy, of unconditionally issuing positive classifications, is represented by the upper right point (1, 1). Points that fall along the diagonal line defined by these extremes also are indicative of a processes having little or no discriminatory power. The point (0, 1) represents perfect classification; points close to the top left corner are indicative of a high discriminatory power process. The point (1,0) represents the scenario of always calling a true negative as positive; because the result can be inverted to get the prefect answer the inference is that the (1,0) result has equivalent discriminatory power to the (0,1) result.




**Appendix Figure 2: ROC graph points falling along the dotted diagonal indicate that the process has little or no discriminatory power. Points falling in the top left or bottom right regions of the graph indicate high discriminatory power.**

## Appendix 4: Predictive discriminatory power of various *TP* and *FP* rates

In the pure mathematical abstraction a QDA confusion table allocation processes where the *TP* and *FP* rates are not equal (i.e. do not fall on the dotted line in Appendix Figure 2) has discriminatory power, i.e. the true sample proportion can be derived from the "observed" QDA sample allocation proportion given that *TP* and *FP* are known without error and $TP \neq FP$. The proof of this is as follows:

Let *nTP* = number of true positives in the sample

Let *N* be the total number in the sample

*TP* and *FP* rates are known constants (e.g. as given in the QDA confusion table)

*TPR* the True Proportion Ratio is given by:

$$TPR = \frac{nTP}{N}$$

*nTP* has *N*+1 unique values coming from the integer set: **I:** {0,1,…,*N*}

Thus *TPR* has *N*+1 unique values and is totally determined by *nTP* thus *TPR* and *nTP* are perfectly linearly correlated.

Let *nOP* be the expected number of “observed” positives in the sample as derived from a QDA confusion table such that:

$$nOP = (TP * nTP) + (FP * (N - nTP))$$

Thus the expected “Observed” Proportion Ratio ($OPR$) in the sample *N* as derived from the QDA is:

$$OPR = \frac{nOP}{N}$$

$OPR$ has *N*+1 unique values and is totally determined by *nOP* if and only if $TP \neq FP$ therefore $OPR$ and *nOP* are perfectly linearly correlated as are *OPR* and *TPR;* meaning that it is possible to estimate *TPR* from the *OPR*, *TP* and *FP,* given that $TP \neq FP$, as follows:

$$OPR = \frac{(TP * TPR * N) + (FP * (N - TPR * N))}{N}$$

$$OPR = \frac{\cancel{N}[(TP * TPR) + \big(FP * (1 - TPR)\big)]}{\cancel{N}}$$

$$OPR = (TP * TPR) + FP - (FP * TPR)$$

$$OPR - FP = TPR[TP - FP]$$

$$TPR = \frac{OPR - FP}{(TP - FP)}$$

However, when *TP* = *FP* *OPR* has only one value (*FP*) for all values of *nTP* thus *OPR* and *TPR* have zero correlation i.e. the confusion table has zero discriminatory power, proof as follows:

$$OPR = \frac{(FP * TPR * N) + (FP * (N - TPR * N))}{N}$$

$$OPR = \frac{FP * \cancel{N}(TPR + 1 - TPR)}{\cancel{N}}$$

$$OPR = FP = TP \quad \text{(for all values of } nTP \ \{0,1,\ldots,N\}\text{)}$$

Under ‘real-world’ sampling constraints the level of precision on the estimate of *TPR* is largely determined by sample size; the perfect discriminatory scenario (*FP* = 0 and *TP* = 1) representing the ‘best case’ or minimum sampling requirement to estimate *TPR* with a given precision of *x*. The discriminatory range of *OPR* diminishes as *FP* and *TP* become closer in value such that the level of precision required on the sample estimate of *OPR*, so as to be a ‘useful’ predictor of *TPR,* increases. As *FP* approaches *NP* in value the sample-size required to estimate *TPR* with a given precision of *x*, as derived from the sample estimate of *OPR,* becomes infinitely large.

**Appendix 5: Derivation of bootstrap 95% confidence bounds on the QDA resolution range for a given sample size of $n$ and a true regional proportion of $p[region]$.**

To account for the underlying uncertainty in the three region QDA allocation tables (Tables 5–7) it was necessary to derive 1000 unique QDA tables by bootstrapping from the original otolith chemical signature set used to generate the three area QDAs (Tables 5–7). This required repeating the entire QDA sequential 'leave one out' allocation step process 1000 times. For each bootstrap each unique otolith from the full dataset was left out in turn according to the standard QDA approach (i.e., the sequence of held back otoliths was not bootstrapped), however otoliths making up the allocation data set were randomly drawn from the remaining otoliths with replacement.

The main bootstrap process was as follows:

1. Given a sample of $n$ otoliths bootstrap the sample 'true proportion' ($p[region]_i$) pursuant to the population true proportion ( $p[region]$ ) where $i$ = the $i$th bootstrap.
2. Randomly draw with replacement from the 1000 bootstrap QDA tables.
3. Randomly draw the FP value from the bootstrap QDA table this being either the maximum or minimum FP value (i.e. 50:50 random draw).
4. Derive an estimate of the observed number of positives in the sample estimates based on the bootstrap true sample proportion and the boot QDA TP and FP values according to Appendix 4.
5. Derive the maximum resolution score from the bootstrap observed positive value and the FP and TP values from the non-bootstrap QDA table (i.e. Tables 5,6 or 7) according to Appendix 4.

**Appendix 6: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range.**

## Bay of Plenty (BPLE)

| True proportion | No sampling variation: lower true predicted value | upper true predicted value | prediction resolution range | Bootstrap 95% CI for a 500 otolith sample: Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.22 | 0.22 | 0.00 | 0.34 | 0.34 | 0.00 |
| 0.1 | 0.00 | 0.30 | 0.30 | 0.00 | 0.34 | 0.34 | 0.01 |
| 0.2 | 0.00 | 0.37 | 0.37 | 0.00 | 0.39 | 0.39 | 0.06 |
| 0.3 | 0.11 | 0.45 | 0.35 | 0.00 | 0.40 | 0.40 | 0.10 |
| 0.4 | 0.23 | 0.53 | 0.30 | 0.00 | 0.46 | 0.46 | 0.15 |
| 0.5 | 0.36 | 0.61 | 0.25 | 0.00 | 0.52 | 0.52 | 0.19 |
| 0.6 | 0.49 | 0.69 | 0.20 | 0.00 | 0.58 | 0.58 | 0.23 |
| 0.7 | 0.62 | 0.77 | 0.15 | 0.00 | 0.67 | 0.67 | 0.28 |
| 0.8 | 0.74 | 0.84 | 0.10 | 0.00 | 0.75 | 0.75 | 0.32 |
| 0.9 | 0.87 | 0.92 | 0.05 | 0.00 | 0.83 | 0.83 | 0.35 |
| 1 | 1.00 | 1.00 | 0.00 | 0.00 | 0.91 | 0.91 | 0.40 |

## East Northland (ENLD)

| True proportion | No sampling variation: lower true predicted value | upper true predicted value | prediction resolution range | Bootstrap 95% CI for a 500 otolith sample: Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.34 | 0.34 | 0.00 | 0.49 | 0.49 | 0.01 |
| 0.1 | 0.00 | 0.40 | 0.40 | 0.00 | 0.54 | 0.54 | 0.10 |
| 0.2 | 0.00 | 0.47 | 0.47 | 0.00 | 0.60 | 0.60 | 0.20 |
| 0.3 | 0.00 | 0.54 | 0.54 | 0.00 | 0.61 | 0.61 | 0.27 |
| 0.4 | 0.09 | 0.60 | 0.51 | 0.00 | 0.66 | 0.66 | 0.36 |
| 0.5 | 0.25 | 0.67 | 0.42 | 0.11 | 0.73 | 0.62 | 0.46 |
| 0.6 | 0.40 | 0.74 | 0.34 | 0.24 | 0.77 | 0.54 | 0.55 |
| 0.7 | 0.55 | 0.80 | 0.25 | 0.36 | 0.82 | 0.45 | 0.63 |
| 0.8 | 0.70 | 0.87 | 0.17 | 0.48 | 0.88 | 0.39 | 0.72 |
| 0.9 | 0.85 | 0.93 | 0.08 | 0.62 | 0.94 | 0.32 | 0.81 |
| 1 | 1.00 | 1.00 | 0.00 | 0.75 | 1.00 | 0.25 | 0.89 |

**Appendix 6: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range cont.**

## Hauraki Gulf (HAGU)

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.72 | 0.72 | 0.00 | 0.94 | 0.94 | 0.03 |
| 0.1 | 0.00 | 0.75 | 0.75 | 0.00 | 0.96 | 0.96 | 0.10 |
| 0.2 | 0.00 | 0.78 | 0.78 | 0.00 | 0.95 | 0.95 | 0.21 |
| 0.3 | 0.00 | 0.81 | 0.81 | 0.00 | 0.96 | 0.96 | 0.29 |
| 0.4 | 0.00 | 0.83 | 0.83 | 0.00 | 0.98 | 0.98 | 0.40 |
| 0.5 | 0.00 | 0.86 | 0.86 | 0.00 | 0.99 | 0.99 | 0.47 |
| 0.6 | 0.00 | 0.89 | 0.89 | 0.00 | 1.00 | 1.00 | 0.58 |
| 0.7 | 0.00 | 0.92 | 0.92 | 0.00 | 1.00 | 1.00 | 0.67 |
| 0.8 | 0.28 | 0.94 | 0.67 | 0.00 | 1.00 | 1.00 | 0.77 |
| 0.9 | 0.64 | 0.97 | 0.33 | 0.09 | 1.00 | 0.91 | 0.86 |
| 1 | 1.00 | 1.00 | 0.00 | 0.35 | 1.00 | 0.65 | 0.94 |

## Kaipara Harbour

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.34 | 0.34 | 0.00 | 0.49 | 0.49 | 0.08 |
| 0.1 | 0.00 | 0.41 | 0.41 | 0.00 | 0.51 | 0.51 | 0.14 |
| 0.2 | 0.00 | 0.47 | 0.47 | 0.00 | 0.54 | 0.54 | 0.20 |
| 0.3 | 0.00 | 0.54 | 0.54 | 0.00 | 0.59 | 0.59 | 0.26 |
| 0.4 | 0.09 | 0.60 | 0.51 | 0.00 | 0.62 | 0.62 | 0.33 |
| 0.5 | 0.24 | 0.67 | 0.43 | 0.00 | 0.66 | 0.66 | 0.38 |
| 0.6 | 0.39 | 0.74 | 0.34 | 0.08 | 0.71 | 0.63 | 0.46 |
| 0.7 | 0.54 | 0.80 | 0.26 | 0.16 | 0.75 | 0.59 | 0.51 |
| 0.8 | 0.70 | 0.87 | 0.17 | 0.25 | 0.80 | 0.56 | 0.58 |
| 0.9 | 0.85 | 0.93 | 0.09 | 0.31 | 0.87 | 0.56 | 0.64 |
| 1 | 1.00 | 1.00 | 0.00 | 0.38 | 0.94 | 0.56 | 0.70 |

**Appendix 6: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range cont.**

## Manukau Harbour

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.56 | 0.56 | 0.00 | 1.00 | 1.00 | 0.00 |
| 0.1 | 0.00 | 0.60 | 0.60 | 0.00 | 1.00 | 1.00 | 0.17 |
| 0.2 | 0.00 | 0.65 | 0.65 | 0.00 | 1.00 | 1.00 | 0.31 |
| 0.3 | 0.00 | 0.69 | 0.69 | 0.00 | 1.00 | 1.00 | 0.39 |
| 0.4 | 0.00 | 0.73 | 0.73 | 0.00 | 1.00 | 1.00 | 0.53 |
| 0.5 | 0.00 | 0.78 | 0.78 | 0.00 | 1.00 | 1.00 | 0.59 |
| 0.6 | 0.10 | 0.82 | 0.72 | 0.00 | 1.00 | 1.00 | 0.72 |
| 0.7 | 0.32 | 0.87 | 0.54 | 0.00 | 1.00 | 1.00 | 0.84 |
| 0.8 | 0.55 | 0.91 | 0.36 | 0.00 | 1.00 | 1.00 | 0.95 |
| 0.9 | 0.77 | 0.96 | 0.18 | 0.00 | 1.00 | 1.00 | 1.00 |
| 1 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 |

## NW Harbours

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 1.81 | 2.24 | 0.43 | 0.00 | 1.00 | 0.99 | 1.00 |
| 0.1 | 1.73 | 2.11 | 0.39 | 0.00 | 1.00 | 1.00 | 1.00 |
| 0.2 | 1.65 | 1.99 | 0.34 | 0.00 | 1.00 | 1.00 | 1.00 |
| 0.3 | 1.57 | 1.87 | 0.30 | 0.00 | 1.00 | 1.00 | 1.00 |
| 0.4 | 1.48 | 1.74 | 0.26 | 0.00 | 1.00 | 1.00 | 1.00 |
| 0.5 | 1.40 | 1.62 | 0.21 | 0.07 | 1.00 | 1.00 | 0.93 |
| 0.6 | 1.32 | 1.50 | 0.17 | 0.20 | 1.00 | 1.00 | 0.80 |
| 0.7 | 1.24 | 1.37 | 0.13 | 0.26 | 1.00 | 1.00 | 0.74 |
| 0.8 | 1.16 | 1.25 | 0.09 | 0.32 | 1.00 | 1.00 | 0.68 |
| 0.9 | 1.08 | 1.12 | 0.04 | 0.29 | 1.00 | 1.00 | 0.71 |
| 1 | 1.00 | 1.00 | 0.00 | 0.27 | 1.00 | 1.00 | 0.73 |

**Appendix 6: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range cont.**

## SW Harbours

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.15 | 0.15 | 0.00 | 0.51 | 0.51 | 0.05 |
| 0.1 | 0.00 | 0.24 | 0.24 | 0.00 | 0.56 | 0.56 | 0.15 |
| 0.2 | 0.06 | 0.32 | 0.26 | 0.00 | 0.65 | 0.65 | 0.24 |
| 0.3 | 0.18 | 0.41 | 0.23 | 0.06 | 0.67 | 0.62 | 0.33 |
| 0.4 | 0.29 | 0.49 | 0.20 | 0.15 | 0.75 | 0.61 | 0.42 |
| 0.5 | 0.41 | 0.58 | 0.16 | 0.24 | 0.84 | 0.59 | 0.52 |
| 0.6 | 0.53 | 0.66 | 0.13 | 0.32 | 0.91 | 0.59 | 0.60 |
| 0.7 | 0.65 | 0.75 | 0.10 | 0.38 | 1.00 | 0.62 | 0.69 |
| 0.8 | 0.76 | 0.83 | 0.07 | 0.46 | 1.00 | 0.54 | 0.78 |
| 0.9 | 0.88 | 0.92 | 0.03 | 0.52 | 1.00 | 0.48 | 0.84 |
| 1 | 1.00 | 1.00 | 0.00 | 0.60 | 1.00 | 0.40 | 0.96 |

**Appendix 7: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range**

## Kaipara Harbour

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.35 | 0.35 | 0.00 | 0.50 | 0.50 | 0.02 |
| 0.1 | 0.00 | 0.42 | 0.42 | 0.00 | 0.54 | 0.54 | 0.10 |
| 0.2 | 0.00 | 0.48 | 0.48 | 0.00 | 0.56 | 0.56 | 0.18 |
| 0.3 | 0.00 | 0.55 | 0.55 | 0.00 | 0.61 | 0.61 | 0.26 |
| 0.4 | 0.07 | 0.61 | 0.54 | 0.00 | 0.66 | 0.66 | 0.34 |
| 0.5 | 0.23 | 0.68 | 0.45 | 0.01 | 0.70 | 0.69 | 0.41 |
| 0.6 | 0.38 | 0.74 | 0.36 | 0.11 | 0.74 | 0.63 | 0.49 |
| 0.7 | 0.54 | 0.81 | 0.27 | 0.23 | 0.80 | 0.57 | 0.57 |
| 0.8 | 0.69 | 0.87 | 0.18 | 0.33 | 0.86 | 0.53 | 0.64 |
| 0.9 | 0.85 | 0.94 | 0.09 | 0.41 | 0.92 | 0.51 | 0.73 |
| 1 | 1.00 | 1.00 | 0.00 | 0.49 | 1.00 | 0.51 | 0.79 |

## Manukau Harbour

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True Proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.30 | 0.30 | 0.00 | 0.33 | 0.33 | 0.00 |
| 0.1 | 0.00 | 0.37 | 0.37 | 0.00 | 0.34 | 0.34 | 0.00 |
| 0.2 | 0.00 | 0.44 | 0.44 | 0.00 | 0.38 | 0.38 | 0.01 |
| 0.3 | 0.00 | 0.51 | 0.51 | 0.00 | 0.43 | 0.43 | 0.07 |
| 0.4 | 0.14 | 0.58 | 0.45 | 0.00 | 0.48 | 0.48 | 0.12 |
| 0.5 | 0.28 | 0.65 | 0.37 | 0.00 | 0.53 | 0.53 | 0.18 |
| 0.6 | 0.43 | 0.72 | 0.30 | 0.00 | 0.59 | 0.59 | 0.23 |
| 0.7 | 0.57 | 0.79 | 0.22 | 0.00 | 0.65 | 0.65 | 0.29 |
| 0.8 | 0.71 | 0.86 | 0.15 | 0.00 | 0.74 | 0.74 | 0.35 |
| 0.9 | 0.86 | 0.93 | 0.07 | 0.00 | 0.80 | 0.80 | 0.41 |
| 1 | 1.00 | 1.00 | 0.00 | 0.00 | 0.88 | 0.88 | 0.45 |

**Appendix 7: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range cont.**

## NE Harbours

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.33 | 0.33 | 0.00 | 0.35 | 0.35 | 0.00 |
| 0.1 | 0.00 | 0.40 | 0.40 | 0.00 | 0.41 | 0.41 | 0.09 |
| 0.2 | 0.00 | 0.47 | 0.47 | 0.00 | 0.47 | 0.47 | 0.17 |
| 0.3 | 0.00 | 0.53 | 0.53 | 0.00 | 0.54 | 0.54 | 0.27 |
| 0.4 | 0.10 | 0.60 | 0.50 | 0.01 | 0.59 | 0.59 | 0.36 |
| 0.5 | 0.25 | 0.67 | 0.42 | 0.13 | 0.66 | 0.53 | 0.45 |
| 0.6 | 0.40 | 0.73 | 0.33 | 0.26 | 0.72 | 0.46 | 0.54 |
| 0.7 | 0.55 | 0.80 | 0.25 | 0.39 | 0.79 | 0.40 | 0.62 |
| 0.8 | 0.70 | 0.87 | 0.17 | 0.50 | 0.86 | 0.36 | 0.72 |
| 0.9 | 0.85 | 0.93 | 0.08 | 0.63 | 0.95 | 0.32 | 0.81 |
| 1 | 1.00 | 1.00 | 0.00 | 0.73 | 1.00 | 0.27 | 0.90 |

## NW Harbours

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.91 | 0.91 | 0.00 | 1.00 | 1.00 | 0.39 |
| 0.1 | 0.00 | 0.92 | 0.92 | 0.00 | 1.00 | 1.00 | 0.46 |
| 0.2 | 0.00 | 0.93 | 0.93 | 0.00 | 1.00 | 1.00 | 0.53 |
| 0.3 | 0.00 | 0.94 | 0.94 | 0.00 | 1.00 | 1.00 | 0.61 |
| 0.4 | 0.00 | 0.95 | 0.95 | 0.00 | 1.00 | 1.00 | 0.71 |
| 0.5 | 0.00 | 0.95 | 0.95 | 0.00 | 1.00 | 1.00 | 0.74 |
| 0.6 | 0.00 | 0.96 | 0.96 | 0.00 | 1.00 | 1.00 | 0.81 |
| 0.7 | 0.00 | 0.97 | 0.97 | 0.00 | 1.00 | 1.00 | 0.83 |
| 0.8 | 0.00 | 0.98 | 0.98 | 0.00 | 1.00 | 1.00 | 0.88 |
| 0.9 | 0.00 | 0.99 | 0.99 | 0.00 | 1.00 | 1.00 | 0.96 |
| 1 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 |

**Appendix 7: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range**

## SW Harbours

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.20 | 0.20 | 0.00 | 0.45 | 0.45 | 0.05 |
| 0.1 | 0.00 | 0.28 | 0.28 | 0.00 | 0.49 | 0.49 | 0.14 |
| 0.2 | 0.00 | 0.36 | 0.36 | 0.00 | 0.53 | 0.53 | 0.23 |
| 0.3 | 0.13 | 0.44 | 0.31 | 0.00 | 0.62 | 0.62 | 0.31 |
| 0.4 | 0.25 | 0.52 | 0.27 | 0.10 | 0.69 | 0.59 | 0.39 |
| 0.5 | 0.38 | 0.60 | 0.22 | 0.19 | 0.75 | 0.56 | 0.47 |
| 0.6 | 0.50 | 0.68 | 0.18 | 0.27 | 0.83 | 0.56 | 0.55 |
| 0.7 | 0.63 | 0.76 | 0.13 | 0.36 | 0.92 | 0.57 | 0.65 |
| 0.8 | 0.75 | 0.84 | 0.09 | 0.44 | 1.00 | 0.56 | 0.73 |
| 0.9 | 0.88 | 0.92 | 0.04 | 0.48 | 1.00 | 0.52 | 0.81 |
| 1 | 1.00 | 1.00 | 0.00 | 0.54 | 1.00 | 0.46 | 0.88 |

**Appendix 8: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range**

## Bay of Plenty (BPLE)

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.21 | 0.21 | 0.00 | 0.32 | 0.32 | 0.00 |
| 0.1 | 0.00 | 0.28 | 0.28 | 0.00 | 0.34 | 0.34 | 0.01 |
| 0.2 | 0.00 | 0.36 | 0.36 | 0.00 | 0.39 | 0.39 | 0.07 |
| 0.3 | 0.12 | 0.44 | 0.32 | 0.00 | 0.44 | 0.44 | 0.11 |
| 0.4 | 0.24 | 0.52 | 0.28 | 0.00 | 0.47 | 0.47 | 0.16 |
| 0.5 | 0.37 | 0.60 | 0.23 | 0.00 | 0.55 | 0.55 | 0.21 |
| 0.6 | 0.50 | 0.68 | 0.19 | 0.00 | 0.63 | 0.63 | 0.26 |
| 0.7 | 0.62 | 0.76 | 0.14 | 0.00 | 0.67 | 0.67 | 0.30 |
| 0.8 | 0.75 | 0.84 | 0.09 | 0.00 | 0.79 | 0.79 | 0.35 |
| 0.9 | 0.87 | 0.92 | 0.05 | 0.00 | 0.88 | 0.88 | 0.40 |
| 1 | 1.00 | 1.00 | 0.00 | 0.00 | 0.96 | 0.96 | 0.48 |

## East Northland (ENLD)

| | No sampling variation | | | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|---|---|---|
| True proportion | lower true predicted value | upper true predicted value | prediction resolution range | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.33 | 0.33 | 0.00 | 0.53 | 0.53 | 0.02 |
| 0.1 | 0.00 | 0.40 | 0.40 | 0.00 | 0.55 | 0.55 | 0.12 |
| 0.2 | 0.00 | 0.47 | 0.47 | 0.00 | 0.60 | 0.60 | 0.20 |
| 0.3 | 0.00 | 0.53 | 0.53 | 0.00 | 0.65 | 0.65 | 0.31 |
| 0.4 | 0.10 | 0.60 | 0.50 | 0.00 | 0.71 | 0.71 | 0.40 |
| 0.5 | 0.25 | 0.67 | 0.42 | 0.13 | 0.76 | 0.63 | 0.49 |
| 0.6 | 0.40 | 0.73 | 0.33 | 0.29 | 0.81 | 0.53 | 0.59 |
| 0.7 | 0.55 | 0.80 | 0.25 | 0.43 | 0.86 | 0.44 | 0.68 |
| 0.8 | 0.70 | 0.87 | 0.17 | 0.56 | 0.93 | 0.37 | 0.78 |
| 0.9 | 0.85 | 0.93 | 0.08 | 0.68 | 1.00 | 0.32 | 0.87 |
| 1 | 1.00 | 1.00 | 0.00 | 0.81 | 1.00 | 0.19 | 0.97 |

**Appendix 8: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range**

## Hauraki Gulf (HAGU)

| True proportion | No sampling variation: lower true predicted value | upper true predicted value | prediction resolution range | Bootstrap 95% CI for a 500 otolith sample: Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.37 | 0.37 | 0.00 | 0.50 | 0.50 | 0.08 |
| 0.1 | 0.00 | 0.43 | 0.43 | 0.00 | 0.55 | 0.55 | 0.17 |
| 0.2 | 0.00 | 0.49 | 0.49 | 0.00 | 0.60 | 0.60 | 0.25 |
| 0.3 | 0.00 | 0.56 | 0.56 | 0.00 | 0.66 | 0.66 | 0.35 |
| 0.4 | 0.05 | 0.62 | 0.56 | 0.00 | 0.71 | 0.71 | 0.43 |
| 0.5 | 0.21 | 0.68 | 0.47 | 0.14 | 0.77 | 0.62 | 0.52 |
| 0.6 | 0.37 | 0.75 | 0.38 | 0.28 | 0.82 | 0.54 | 0.61 |
| 0.7 | 0.53 | 0.81 | 0.28 | 0.42 | 0.87 | 0.46 | 0.70 |
| 0.8 | 0.68 | 0.87 | 0.19 | 0.55 | 0.95 | 0.40 | 0.79 |
| 0.9 | 0.84 | 0.94 | 0.09 | 0.68 | 1.00 | 0.32 | 0.88 |
| 1 | 1.00 | 1.00 | 0.00 | 0.78 | 1.00 | 0.22 | 0.96 |

## NW Harbours

| True proportion | No sampling variation: lower true predicted value | upper true predicted value | prediction resolution range | Bootstrap 95% CI for a 500 otolith sample: Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.96 | 0.96 | 0.00 | 1.00 | 1.00 | 0.13 |
| 0.1 | 0.00 | 0.96 | 0.96 | 0.00 | 1.00 | 1.00 | 0.23 |
| 0.2 | 0.00 | 0.96 | 0.96 | 0.00 | 1.00 | 1.00 | 0.33 |
| 0.3 | 0.00 | 0.97 | 0.97 | 0.00 | 1.00 | 1.00 | 0.48 |
| 0.4 | 0.00 | 0.97 | 0.97 | 0.00 | 1.00 | 1.00 | 0.56 |
| 0.5 | 0.00 | 0.98 | 0.98 | 0.00 | 1.00 | 1.00 | 0.60 |
| 0.6 | 0.00 | 0.98 | 0.98 | 0.00 | 1.00 | 1.00 | 0.80 |
| 0.7 | 0.00 | 0.99 | 0.99 | 0.00 | 1.00 | 1.00 | 0.79 |
| 0.8 | 0.00 | 0.99 | 0.99 | 0.00 | 1.00 | 1.00 | 0.87 |
| 0.9 | 0.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 0.96 |
| 1 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 |

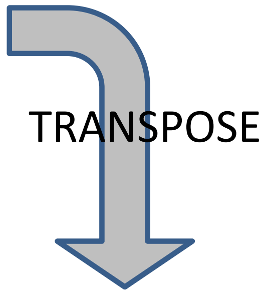
## Appendix 9: Bootstrap derivation of "true" proportional density distributions for given QDA "observed" values

Pursuant to the bootstrap process given in Appendix 5, 1000 random "Observed" ratios are generated for each 0.01 true proportional increment between 0.0 and 1.0 for each natal region, i.e. a uniform number of observed values across the entire range of true values. These bootstraps describe the expected density range of QDA "observed" predicted proportions at each "true" proportion as a frequency matrix (example Appendix Figure 3a). Transposition of this matrix gives the "true" proportion density corresponding to each given QDA "observed" proportion level (example Appendix Figure 3b).

**Appendix Figure 3: Transposition of the matrix of the "true" vs "observed" bootstrap frequency matrix to derive "true" proportion densities for each given QDA "observed" proportion.**

a. Matrix of "Observed" QDA proportion bootstrap frequencies at each 0.01 degree "true" sample

| "True" sample proportion | QDA "Observed" proportion | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.16 | 0.18 | 0.19 | 0.2 | … | 0.76 | 0.77 | 0.78 | 0.79 | 0.8 |
| 0 | 0 | 3 | 5 | 6 | … | 0 | 0 | 0 | 0 | 0 |
| 0.01 | 0 | 1 | 2 | 5 | … | 0 | 0 | 0 | 0 | 0 |
| 0.02 | 0 | 1 | 4 | 1 | … | 0 | 0 | 0 | 0 | 0 |
| 0.03 | 1 | 0 | 0 | 2 | … | 0 | 0 | 0 | 0 | 0 |
| 0.04 | 0 | 0 | 1 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| 0.05 | 0 | 0 | 1 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| 0.06 | 0 | 0 | 0 | 1 | … | 0 | 0 | 0 | 0 | 0 |
| 0.07 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| 0.08 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| 0.09 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| 0.1 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| 0.11 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 0.9 | 0 | 0 | 0 | 0 | … | 9 | 4 | 1 | 0 | 0 |
| 0.91 | 0 | 0 | 0 | 0 | … | 13 | 1 | 0 | 0 | 0 |
| 0.92 | 0 | 0 | 0 | 0 | … | 9 | 7 | 1 | 0 | 0 |
| 0.93 | 0 | 0 | 0 | 0 | … | 15 | 9 | 4 | 2 | 0 |
| 0.94 | 0 | 0 | 0 | 0 | … | 20 | 12 | 6 | 1 | 0 |
| 0.95 | 0 | 0 | 0 | 0 | … | 24 | 18 | 4 | 4 | 0 |
| 0.96 | 0 | 0 | 0 | 0 | … | 39 | 12 | 7 | 2 | 2 |
| 0.97 | 0 | 0 | 0 | 0 | … | 41 | 23 | 12 | 5 | 2 |
| 0.98 | 0 | 0 | 0 | 0 | … | 61 | 32 | 11 | 6 | 4 |
| 0.99 | 0 | 0 | 0 | 0 | … | 45 | 29 | 21 | 9 | 2 |
| 1 | 0 | 0 | 0 | 0 | … | 63 | 42 | 18 | 12 | 3 |




b. Matrix of "true" sample proportions at each 0.01 degree QDA "observed" proportion level

| QDA "Observed" proportion | "True" sample proportion | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.1 | 0.11 | … | 0.9 | 0.91 | 0.92 | 0.93 | 0.94 | 0.95 | 0.96 | 0.97 | 0.98 | 0.99 | 1 |
| 0.16 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.18 | 3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.19 | 5 | 2 | 4 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.2 | 6 | 5 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 0.76 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 9 | 13 | 9 | 15 | 20 | 24 | 39 | 41 | 61 | 45 | 63 |
| 0.77 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 4 | 1 | 7 | 9 | 12 | 18 | 12 | 23 | 32 | 29 | 42 |
| 0.78 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 1 | 0 | 1 | 4 | 6 | 4 | 7 | 12 | 11 | 21 | 18 |
| 0.79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 2 | 1 | 4 | 2 | 5 | 6 | 9 | 12 |
| 0.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | … | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 2 | 3 |

**Appendix 10: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Bay of Plenty (BPLE)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed Proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0 | 0.00 | 0.95 | 0.95 | 0.04 |
| 0.01 | 0.00 | 0.74 | 0.74 | 0.11 |
| 0.02 | 0.02 | 0.92 | 0.90 | 0.20 |
| 0.03 | 0.02 | 0.95 | 0.93 | 0.29 |
| 0.04 | 0.02 | 0.90 | 0.88 | 0.33 |
| 0.05 | 0.02 | 0.90 | 0.88 | 0.36 |
| 0.06 | 0.02 | 0.95 | 0.93 | 0.42 |
| 0.07 | 0.03 | 0.97 | 0.94 | 0.47 |
| 0.08 | 0.04 | 0.97 | 0.93 | 0.52 |
| 0.09 | 0.06 | 0.98 | 0.92 | 0.57 |
| 0.1 | 0.10 | 0.98 | 0.88 | 0.62 |
| 0.11 | 0.15 | 0.99 | 0.84 | 0.66 |
| 0.12 | 0.23 | 0.99 | 0.76 | 0.71 |
| 0.13 | 0.32 | 0.99 | 0.67 | 0.77 |
| 0.14 | 0.40 | 1.00 | 0.60 | 0.81 |
| 0.15 | 0.46 | 1.00 | 0.54 | 0.84 |
| 0.16 | 0.51 | 1.00 | 0.49 | 0.86 |
| 0.17 | 0.55 | 1.00 | 0.45 | 0.87 |
| 0.18 | 0.59 | 1.00 | 0.41 | 0.88 |
| 0.19 | 0.63 | 1.00 | 0.37 | 0.88 |
| 0.2 | 0.65 | 1.00 | 0.35 | 0.90 |
| 0.21 | 0.69 | 1.00 | 0.31 | 0.91 |
| 0.22 | 0.73 | 1.00 | 0.27 | 0.92 |
| 0.23 | 0.76 | 1.00 | 0.24 | 0.93 |
| 0.24 | 0.75 | 1.00 | 0.25 | 0.94 |
| 0.25 | 0.80 | 1.00 | 0.20 | 0.95 |
| 0.26 | 0.81 | 1.00 | 0.19 | 0.95 |
| 0.27 | 0.85 | 1.00 | 0.15 | 0.96 |
| 0.28 | 0.81 | 1.00 | 0.19 | 0.97 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## East Northland (ENLD)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.06 | 0.00 | 0.04 | 0.04 | 0.01 |
| 0.07 | 0.00 | 0.05 | 0.05 | 0.01 |
| 0.08 | 0.00 | 0.06 | 0.06 | 0.01 |
| 0.09 | 0.00 | 0.07 | 0.07 | 0.02 |
| 0.1 | 0.00 | 0.08 | 0.08 | 0.02 |
| 0.11 | 0.00 | 0.09 | 0.09 | 0.02 |
| 0.12 | 0.00 | 0.10 | 0.10 | 0.02 |
| 0.13 | 0.00 | 0.11 | 0.11 | 0.03 |
| 0.14 | 0.00 | 0.13 | 0.13 | 0.03 |
| 0.15 | 0.00 | 0.13 | 0.13 | 0.04 |
| 0.16 | 0.00 | 0.14 | 0.14 | 0.04 |
| 0.17 | 0.00 | 0.16 | 0.16 | 0.05 |
| 0.18 | 0.00 | 0.17 | 0.17 | 0.06 |
| 0.19 | 0.00 | 0.19 | 0.19 | 0.07 |
| 0.2 | 0.00 | 0.20 | 0.20 | 0.08 |
| 0.21 | 0.00 | 0.22 | 0.22 | 0.10 |
| 0.22 | 0.01 | 0.24 | 0.23 | 0.11 |
| 0.23 | 0.02 | 0.25 | 0.23 | 0.13 |
| 0.24 | 0.02 | 0.27 | 0.25 | 0.15 |
| 0.25 | 0.03 | 0.29 | 0.26 | 0.17 |
| 0.26 | 0.03 | 0.30 | 0.27 | 0.19 |
| 0.27 | 0.02 | 0.32 | 0.30 | 0.21 |
| 0.28 | 0.01 | 0.34 | 0.33 | 0.22 |
| 0.29 | 0.01 | 0.36 | 0.35 | 0.24 |
| 0.3 | 0.00 | 0.38 | 0.38 | 0.25 |
| 0.31 | 0.00 | 0.39 | 0.39 | 0.26 |
| 0.32 | 0.00 | 0.41 | 0.41 | 0.28 |
| 0.33 | 0.01 | 0.43 | 0.42 | 0.28 |
| 0.34 | 0.01 | 0.44 | 0.43 | 0.29 |
| 0.35 | 0.01 | 0.46 | 0.45 | 0.30 |
| 0.36 | 0.01 | 0.48 | 0.47 | 0.30 |
| 0.37 | 0.01 | 0.50 | 0.49 | 0.31 |
| 0.38 | 0.01 | 0.51 | 0.50 | 0.31 |
| 0.39 | 0.02 | 0.53 | 0.51 | 0.31 |
| 0.4 | 0.02 | 0.55 | 0.53 | 0.32 |
| 0.41 | 0.02 | 0.57 | 0.55 | 0.33 |
| 0.42 | 0.03 | 0.59 | 0.56 | 0.35 |
| 0.43 | 0.04 | 0.61 | 0.57 | 0.37 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## East Northland (ENLD)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.44 | 0.05 | 0.63 | 0.58 | 0.39 |
| 0.45 | 0.06 | 0.64 | 0.58 | 0.42 |
| 0.46 | 0.08 | 0.67 | 0.59 | 0.44 |
| 0.47 | 0.09 | 0.69 | 0.60 | 0.47 |
| 0.48 | 0.10 | 0.70 | 0.60 | 0.49 |
| 0.49 | 0.13 | 0.72 | 0.59 | 0.52 |
| 0.5 | 0.16 | 0.75 | 0.59 | 0.55 |
| 0.51 | 0.18 | 0.77 | 0.59 | 0.57 |
| 0.52 | 0.21 | 0.79 | 0.58 | 0.60 |
| 0.53 | 0.25 | 0.81 | 0.56 | 0.63 |
| 0.54 | 0.28 | 0.83 | 0.55 | 0.66 |
| 0.55 | 0.32 | 0.85 | 0.53 | 0.68 |
| 0.56 | 0.36 | 0.87 | 0.51 | 0.71 |
| 0.57 | 0.40 | 0.89 | 0.49 | 0.74 |
| 0.58 | 0.45 | 0.92 | 0.47 | 0.76 |
| 0.59 | 0.50 | 0.94 | 0.44 | 0.79 |
| 0.6 | 0.54 | 0.96 | 0.42 | 0.81 |
| 0.61 | 0.59 | 0.98 | 0.39 | 0.84 |
| 0.62 | 0.63 | 0.99 | 0.36 | 0.86 |
| 0.63 | 0.67 | 0.99 | 0.32 | 0.89 |
| 0.64 | 0.71 | 1.00 | 0.29 | 0.91 |
| 0.65 | 0.74 | 1.00 | 0.26 | 0.92 |
| 0.66 | 0.77 | 1.00 | 0.23 | 0.94 |
| 0.67 | 0.80 | 1.00 | 0.20 | 0.95 |
| 0.68 | 0.82 | 1.00 | 0.18 | 0.96 |
| 0.69 | 0.85 | 1.00 | 0.15 | 0.97 |
| 0.7 | 0.87 | 1.00 | 0.13 | 0.97 |
| 0.71 | 0.88 | 1.00 | 0.12 | 0.98 |
| 0.72 | 0.89 | 1.00 | 0.11 | 0.98 |
| 0.73 | 0.90 | 1.00 | 0.10 | 0.99 |
| 0.74 | 0.92 | 1.00 | 0.08 | 0.99 |
| 0.75 | 0.93 | 1.00 | 0.07 | 0.99 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Hauraki Gulf (HAGU)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.02 | 0.02 | 0.01 |
| 0.01 | 0.00 | 0.04 | 0.04 | 0.02 |
| 0.02 | 0.00 | 0.06 | 0.06 | 0.03 |
| 0.03 | 0.00 | 0.08 | 0.08 | 0.01 |
| 0.04 | 0.00 | 0.10 | 0.10 | 0.03 |
| 0.05 | 0.00 | 0.12 | 0.12 | 0.05 |
| 0.06 | 0.00 | 0.13 | 0.13 | 0.05 |
| 0.07 | 0.00 | 0.15 | 0.15 | 0.04 |
| 0.08 | 0.00 | 0.17 | 0.17 | 0.04 |
| 0.09 | 0.00 | 0.18 | 0.18 | 0.05 |
| 0.1 | 0.00 | 0.20 | 0.20 | 0.05 |
| 0.11 | 0.00 | 0.21 | 0.21 | 0.06 |
| 0.12 | 0.00 | 0.23 | 0.23 | 0.07 |
| 0.13 | 0.00 | 0.25 | 0.25 | 0.08 |
| 0.14 | 0.00 | 0.27 | 0.27 | 0.10 |
| 0.15 | 0.00 | 0.29 | 0.29 | 0.11 |
| 0.16 | 0.01 | 0.31 | 0.30 | 0.13 |
| 0.17 | 0.02 | 0.33 | 0.31 | 0.16 |
| 0.18 | 0.04 | 0.36 | 0.32 | 0.18 |
| 0.19 | 0.06 | 0.38 | 0.32 | 0.21 |
| 0.2 | 0.08 | 0.40 | 0.32 | 0.24 |
| 0.21 | 0.11 | 0.43 | 0.32 | 0.26 |
| 0.22 | 0.14 | 0.46 | 0.32 | 0.29 |
| 0.23 | 0.17 | 0.49 | 0.32 | 0.32 |
| 0.24 | 0.19 | 0.51 | 0.32 | 0.35 |
| 0.25 | 0.22 | 0.54 | 0.32 | 0.37 |
| 0.26 | 0.23 | 0.56 | 0.33 | 0.40 |
| 0.27 | 0.22 | 0.59 | 0.37 | 0.43 |
| 0.28 | 0.07 | 0.62 | 0.55 | 0.45 |
| 0.29 | 0.05 | 0.64 | 0.59 | 0.48 |
| 0.3 | 0.03 | 0.68 | 0.65 | 0.50 |
| 0.31 | 0.02 | 0.70 | 0.68 | 0.52 |
| 0.32 | 0.02 | 0.73 | 0.71 | 0.54 |
| 0.33 | 0.01 | 0.75 | 0.74 | 0.56 |
| 0.34 | 0.01 | 0.78 | 0.77 | 0.56 |
| 0.35 | 0.01 | 0.81 | 0.80 | 0.57 |
| 0.36 | 0.02 | 0.83 | 0.81 | 0.56 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Hauraki Gulf (HAGU)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.37 | 0.01 | 0.86 | 0.85 | 0.53 |
| 0.38 | 0.02 | 0.89 | 0.87 | 0.50 |
| 0.39 | 0.02 | 0.91 | 0.89 | 0.50 |
| 0.4 | 0.03 | 0.93 | 0.90 | 0.52 |
| 0.41 | 0.03 | 0.95 | 0.92 | 0.55 |
| 0.42 | 0.04 | 0.97 | 0.93 | 0.58 |
| 0.43 | 0.05 | 0.98 | 0.93 | 0.62 |
| 0.44 | 0.05 | 0.98 | 0.93 | 0.66 |
| 0.45 | 0.06 | 0.99 | 0.93 | 0.69 |
| 0.46 | 0.07 | 0.99 | 0.92 | 0.72 |
| 0.47 | 0.08 | 0.99 | 0.91 | 0.75 |
| 0.48 | 0.09 | 1.00 | 0.91 | 0.78 |
| 0.49 | 0.11 | 1.00 | 0.89 | 0.82 |
| 0.5 | 0.13 | 1.00 | 0.87 | 0.84 |
| 0.51 | 0.12 | 1.00 | 0.88 | 0.87 |
| 0.52 | 0.11 | 1.00 | 0.89 | 0.88 |
| 0.53 | 0.12 | 1.00 | 0.88 | 0.90 |
| 0.54 | 0.12 | 1.00 | 0.88 | 0.92 |
| 0.55 | 0.10 | 1.00 | 0.90 | 0.93 |
| 0.56 | 0.09 | 1.00 | 0.91 | 0.94 |
| 0.57 | 0.09 | 1.00 | 0.91 | 0.95 |
| 0.58 | 0.09 | 1.00 | 0.91 | 0.94 |
| 0.59 | 0.07 | 1.00 | 0.93 | 0.92 |
| 0.6 | 0.02 | 1.00 | 0.98 | 0.71 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Kaipara harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.03 | 0.03 | 0.01 |
| 0.01 | 0.00 | 0.07 | 0.07 | 0.03 |
| 0.02 | 0.00 | 0.10 | 0.10 | 0.05 |
| 0.03 | 0.00 | 0.13 | 0.13 | 0.03 |
| 0.04 | 0.00 | 0.15 | 0.15 | 0.04 |
| 0.05 | 0.00 | 0.19 | 0.19 | 0.06 |
| 0.06 | 0.00 | 0.22 | 0.22 | 0.09 |
| 0.07 | 0.00 | 0.25 | 0.25 | 0.11 |
| 0.08 | 0.01 | 0.28 | 0.27 | 0.14 |
| 0.09 | 0.03 | 0.32 | 0.29 | 0.17 |
| 0.1 | 0.05 | 0.36 | 0.31 | 0.20 |
| 0.11 | 0.07 | 0.40 | 0.33 | 0.23 |
| 0.12 | 0.04 | 0.44 | 0.40 | 0.26 |
| 0.13 | 0.02 | 0.48 | 0.46 | 0.29 |
| 0.14 | 0.01 | 0.51 | 0.50 | 0.31 |
| 0.15 | 0.01 | 0.55 | 0.54 | 0.33 |
| 0.16 | 0.01 | 0.58 | 0.57 | 0.34 |
| 0.17 | 0.01 | 0.62 | 0.61 | 0.35 |
| 0.18 | 0.01 | 0.66 | 0.65 | 0.35 |
| 0.19 | 0.01 | 0.70 | 0.69 | 0.35 |
| 0.2 | 0.02 | 0.73 | 0.71 | 0.36 |
| 0.21 | 0.02 | 0.77 | 0.75 | 0.38 |
| 0.22 | 0.03 | 0.81 | 0.78 | 0.42 |
| 0.23 | 0.05 | 0.85 | 0.80 | 0.46 |
| 0.24 | 0.07 | 0.89 | 0.82 | 0.51 |
| 0.25 | 0.11 | 0.92 | 0.81 | 0.56 |
| 0.26 | 0.15 | 0.94 | 0.79 | 0.60 |
| 0.27 | 0.20 | 0.96 | 0.76 | 0.64 |
| 0.28 | 0.26 | 0.97 | 0.71 | 0.69 |
| 0.29 | 0.31 | 0.98 | 0.67 | 0.72 |
| 0.3 | 0.36 | 0.99 | 0.63 | 0.76 |
| 0.31 | 0.42 | 0.99 | 0.57 | 0.79 |
| 0.32 | 0.47 | 0.99 | 0.52 | 0.82 |
| 0.33 | 0.51 | 1.00 | 0.49 | 0.84 |
| 0.34 | 0.56 | 1.00 | 0.44 | 0.86 |
| 0.35 | 0.59 | 1.00 | 0.41 | 0.88 |
| 0.36 | 0.63 | 1.00 | 0.37 | 0.90 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Kaipara harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.37 | 0.66 | 1.00 | 0.34 | 0.91 |
| 0.38 | 0.70 | 1.00 | 0.30 | 0.92 |
| 0.39 | 0.73 | 1.00 | 0.27 | 0.93 |
| 0.4 | 0.74 | 1.00 | 0.26 | 0.94 |
| 0.41 | 0.77 | 1.00 | 0.23 | 0.95 |
| 0.42 | 0.78 | 1.00 | 0.22 | 0.95 |
| 0.43 | 0.82 | 1.00 | 0.18 | 0.96 |
| 0.44 | 0.83 | 1.00 | 0.17 | 0.96 |
| 0.45 | 0.84 | 1.00 | 0.16 | 0.97 |
| 0.46 | 0.86 | 1.00 | 0.14 | 0.97 |
| 0.47 | 0.89 | 1.00 | 0.11 | 0.97 |

## Manukau harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.59 | 0.59 | 0.03 |
| 0.01 | 0.01 | 0.54 | 0.53 | 0.11 |
| 0.02 | 0.02 | 0.82 | 0.80 | 0.20 |
| 0.03 | 0.04 | 0.93 | 0.89 | 0.29 |
| 0.04 | 0.04 | 0.95 | 0.91 | 0.37 |
| 0.05 | 0.02 | 0.96 | 0.94 | 0.42 |
| 0.06 | 0.02 | 0.95 | 0.93 | 0.44 |
| 0.07 | 0.02 | 0.96 | 0.94 | 0.46 |
| 0.08 | 0.02 | 0.97 | 0.95 | 0.48 |
| 0.09 | 0.03 | 0.97 | 0.94 | 0.52 |
| 0.1 | 0.05 | 0.98 | 0.93 | 0.58 |
| 0.11 | 0.07 | 0.98 | 0.91 | 0.64 |
| 0.12 | 0.10 | 0.99 | 0.89 | 0.69 |
| 0.13 | 0.13 | 0.99 | 0.86 | 0.73 |
| 0.14 | 0.19 | 0.99 | 0.80 | 0.77 |
| 0.15 | 0.26 | 1.00 | 0.74 | 0.80 |
| 0.16 | 0.35 | 1.00 | 0.65 | 0.84 |
| 0.17 | 0.42 | 1.00 | 0.58 | 0.86 |
| 0.18 | 0.48 | 1.00 | 0.52 | 0.87 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Manukau harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.19 | 0.54 | 1.00 | 0.46 | 0.87 |
| 0.2 | 0.58 | 1.00 | 0.42 | 0.88 |
| 0.21 | 0.60 | 1.00 | 0.40 | 0.89 |
| 0.22 | 0.65 | 1.00 | 0.35 | 0.90 |
| 0.23 | 0.69 | 1.00 | 0.31 | 0.92 |
| 0.24 | 0.73 | 1.00 | 0.27 | 0.93 |
| 0.25 | 0.73 | 1.00 | 0.27 | 0.94 |
| 0.26 | 0.77 | 1.00 | 0.23 | 0.95 |
| 0.27 | 0.80 | 1.00 | 0.20 | 0.95 |
| 0.28 | 0.79 | 1.00 | 0.21 | 0.94 |

## NW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.02 | 0.00 | 0.17 | 0.17 | 0.03 |
| 0.03 | 0.00 | 0.24 | 0.24 | 0.04 |
| 0.04 | 0.00 | 0.37 | 0.37 | 0.06 |
| 0.05 | 0.00 | 0.48 | 0.48 | 0.09 |
| 0.06 | 0.00 | 0.58 | 0.58 | 0.13 |
| 0.07 | 0.01 | 0.72 | 0.71 | 0.18 |
| 0.08 | 0.01 | 0.84 | 0.83 | 0.25 |
| 0.09 | 0.03 | 0.92 | 0.89 | 0.33 |
| 0.1 | 0.07 | 0.96 | 0.89 | 0.42 |
| 0.11 | 0.13 | 0.97 | 0.84 | 0.51 |
| 0.12 | 0.20 | 0.98 | 0.78 | 0.59 |
| 0.13 | 0.27 | 0.99 | 0.72 | 0.67 |
| 0.14 | 0.29 | 0.99 | 0.70 | 0.74 |
| 0.15 | 0.26 | 0.99 | 0.73 | 0.77 |
| 0.16 | 0.18 | 0.99 | 0.81 | 0.78 |
| 0.17 | 0.13 | 0.99 | 0.86 | 0.77 |
| 0.18 | 0.10 | 0.99 | 0.89 | 0.74 |
| 0.19 | 0.08 | 0.99 | 0.91 | 0.71 |
| 0.2 | 0.06 | 0.99 | 0.93 | 0.66 |
| 0.21 | 0.05 | 0.99 | 0.94 | 0.60 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## NW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.22 | 0.03 | 0.98 | 0.95 | 0.54 |
| 0.23 | 0.03 | 0.97 | 0.94 | 0.49 |
| 0.24 | 0.02 | 0.97 | 0.95 | 0.45 |
| 0.25 | 0.02 | 0.95 | 0.93 | 0.39 |
| 0.26 | 0.02 | 0.93 | 0.91 | 0.35 |
| 0.27 | 0.01 | 0.90 | 0.89 | 0.31 |
| 0.28 | 0.01 | 0.85 | 0.84 | 0.27 |
| 0.29 | 0.01 | 0.79 | 0.78 | 0.24 |
| 0.3 | 0.01 | 0.72 | 0.71 | 0.20 |
| 0.31 | 0.00 | 0.63 | 0.63 | 0.18 |
| 0.32 | 0.00 | 0.58 | 0.58 | 0.16 |
| 0.33 | 0.00 | 0.53 | 0.53 | 0.14 |
| 0.34 | 0.00 | 0.46 | 0.46 | 0.12 |
| 0.35 | 0.00 | 0.41 | 0.41 | 0.11 |
| 0.36 | 0.00 | 0.37 | 0.37 | 0.10 |
| 0.37 | 0.00 | 0.34 | 0.34 | 0.09 |
| 0.38 | 0.00 | 0.33 | 0.33 | 0.08 |
| 0.39 | 0.00 | 0.29 | 0.29 | 0.07 |
| 0.4 | 0.00 | 0.29 | 0.29 | 0.06 |
| 0.41 | 0.00 | 0.31 | 0.31 | 0.07 |
| 0.42 | 0.00 | 0.27 | 0.27 | 0.06 |

## SW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0 | 0.00 | 0.04 | 0.04 | 0.01 |
| 0.01 | 0.00 | 0.09 | 0.09 | 0.03 |
| 0.02 | 0.00 | 0.14 | 0.14 | 0.05 |
| 0.03 | 0.00 | 0.19 | 0.19 | 0.07 |
| 0.04 | 0.01 | 0.24 | 0.23 | 0.11 |
| 0.05 | 0.01 | 0.29 | 0.28 | 0.14 |
| 0.06 | 0.01 | 0.35 | 0.34 | 0.18 |
| 0.07 | 0.01 | 0.40 | 0.39 | 0.20 |
| 0.08 | 0.01 | 0.45 | 0.44 | 0.22 |
| 0.09 | 0.01 | 0.50 | 0.49 | 0.25 |

**Appendix 10 cont.: All GMU 1 region QDA (Table 5) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## SW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.1 | 0.01 | 0.56 | 0.55 | 0.28 |
| 0.11 | 0.02 | 0.62 | 0.60 | 0.31 |
| 0.12 | 0.04 | 0.68 | 0.64 | 0.35 |
| 0.13 | 0.05 | 0.75 | 0.70 | 0.40 |
| 0.14 | 0.07 | 0.81 | 0.74 | 0.44 |
| 0.15 | 0.08 | 0.85 | 0.77 | 0.49 |
| 0.16 | 0.11 | 0.90 | 0.79 | 0.53 |
| 0.17 | 0.15 | 0.94 | 0.79 | 0.58 |
| 0.18 | 0.19 | 0.96 | 0.77 | 0.62 |
| 0.19 | 0.24 | 0.97 | 0.73 | 0.66 |
| 0.2 | 0.30 | 0.98 | 0.68 | 0.70 |
| 0.21 | 0.34 | 0.99 | 0.65 | 0.74 |
| 0.22 | 0.40 | 0.99 | 0.59 | 0.77 |
| 0.23 | 0.43 | 0.99 | 0.56 | 0.79 |
| 0.24 | 0.48 | 0.99 | 0.51 | 0.82 |
| 0.25 | 0.53 | 1.00 | 0.47 | 0.84 |
| 0.26 | 0.57 | 1.00 | 0.43 | 0.86 |
| 0.27 | 0.61 | 1.00 | 0.39 | 0.88 |
| 0.28 | 0.65 | 1.00 | 0.35 | 0.90 |
| 0.29 | 0.68 | 1.00 | 0.32 | 0.91 |
| 0.3 | 0.71 | 1.00 | 0.29 | 0.93 |
| 0.31 | 0.73 | 1.00 | 0.27 | 0.93 |
| 0.32 | 0.74 | 1.00 | 0.26 | 0.94 |
| 0.33 | 0.77 | 1.00 | 0.23 | 0.95 |
| 0.34 | 0.79 | 1.00 | 0.21 | 0.95 |
| 0.35 | 0.82 | 1.00 | 0.18 | 0.96 |
| 0.36 | 0.81 | 1.00 | 0.19 | 0.96 |
| 0.37 | 0.84 | 1.00 | 0.16 | 0.96 |
| 0.38 | 0.86 | 1.00 | 0.14 | 0.97 |
| 0.39 | 0.88 | 1.00 | 0.12 | 0.97 |
| 0.4 | 0.89 | 1.00 | 0.11 | 0.98 |

**Appendix 11: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## Kaipara harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.04 | 0.00 | 0.06 | 0.06 | 0.01 |
| 0.05 | 0.00 | 0.09 | 0.09 | 0.02 |
| 0.06 | 0.00 | 0.09 | 0.09 | 0.02 |
| 0.07 | 0.00 | 0.10 | 0.10 | 0.03 |
| 0.08 | 0.00 | 0.12 | 0.12 | 0.04 |
| 0.09 | 0.00 | 0.15 | 0.15 | 0.05 |
| 0.1 | 0.00 | 0.16 | 0.16 | 0.07 |
| 0.11 | 0.00 | 0.18 | 0.18 | 0.09 |
| 0.12 | 0.01 | 0.22 | 0.21 | 0.10 |
| 0.13 | 0.01 | 0.23 | 0.22 | 0.12 |
| 0.14 | 0.02 | 0.25 | 0.23 | 0.14 |
| 0.15 | 0.04 | 0.28 | 0.24 | 0.17 |
| 0.16 | 0.05 | 0.31 | 0.26 | 0.18 |
| 0.17 | 0.08 | 0.32 | 0.24 | 0.21 |
| 0.18 | 0.10 | 0.36 | 0.26 | 0.23 |
| 0.19 | 0.10 | 0.38 | 0.28 | 0.25 |
| 0.2 | 0.08 | 0.41 | 0.33 | 0.28 |
| 0.21 | 0.04 | 0.43 | 0.39 | 0.30 |
| 0.22 | 0.01 | 0.45 | 0.44 | 0.31 |
| 0.23 | 0.01 | 0.48 | 0.47 | 0.34 |
| 0.24 | 0.00 | 0.50 | 0.50 | 0.35 |
| 0.25 | 0.01 | 0.53 | 0.52 | 0.36 |
| 0.26 | 0.00 | 0.55 | 0.55 | 0.37 |
| 0.27 | 0.01 | 0.57 | 0.56 | 0.37 |
| 0.28 | 0.00 | 0.61 | 0.61 | 0.37 |
| 0.29 | 0.01 | 0.63 | 0.62 | 0.33 |
| 0.3 | 0.01 | 0.63 | 0.62 | 0.33 |
| 0.31 | 0.01 | 0.66 | 0.65 | 0.29 |
| 0.32 | 0.02 | 0.69 | 0.67 | 0.32 |
| 0.33 | 0.02 | 0.71 | 0.69 | 0.35 |
| 0.34 | 0.04 | 0.75 | 0.71 | 0.39 |
| 0.35 | 0.06 | 0.78 | 0.72 | 0.42 |
| 0.36 | 0.07 | 0.80 | 0.73 | 0.46 |
| 0.37 | 0.10 | 0.84 | 0.74 | 0.49 |
| 0.38 | 0.14 | 0.87 | 0.73 | 0.54 |
| 0.39 | 0.18 | 0.88 | 0.70 | 0.58 |
| 0.4 | 0.23 | 0.92 | 0.69 | 0.61 |
| 0.41 | 0.26 | 0.94 | 0.68 | 0.65 |
| 0.42 | 0.31 | 0.96 | 0.65 | 0.69 |

**Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## Kaipara harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.43 | 0.34 | 0.97 | 0.63 | 0.71 |
| 0.44 | 0.39 | 0.97 | 0.58 | 0.75 |
| 0.45 | 0.42 | 0.99 | 0.57 | 0.77 |
| 0.46 | 0.47 | 0.99 | 0.52 | 0.80 |
| 0.47 | 0.52 | 0.99 | 0.47 | 0.83 |
| 0.48 | 0.55 | 0.99 | 0.44 | 0.84 |
| 0.49 | 0.58 | 1.00 | 0.42 | 0.86 |
| 0.5 | 0.61 | 1.00 | 0.39 | 0.88 |
| 0.51 | 0.64 | 1.00 | 0.36 | 0.90 |
| 0.52 | 0.68 | 1.00 | 0.32 | 0.91 |
| 0.53 | 0.69 | 1.00 | 0.31 | 0.92 |
| 0.54 | 0.72 | 1.00 | 0.28 | 0.93 |
| 0.55 | 0.74 | 1.00 | 0.26 | 0.94 |
| 0.56 | 0.76 | 1.00 | 0.24 | 0.95 |
| 0.57 | 0.77 | 1.00 | 0.23 | 0.95 |
| 0.58 | 0.78 | 1.00 | 0.22 | 0.95 |
| 0.59 | 0.79 | 1.00 | 0.21 | 0.95 |
| 0.6 | 0.84 | 1.00 | 0.16 | 0.96 |

## Manukau harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.01 | 0.00 | 0.09 | 0.09 | 0.02 |
| 0.02 | 0.00 | 0.16 | 0.16 | 0.04 |
| 0.03 | 0.00 | 0.21 | 0.21 | 0.06 |
| 0.04 | 0.00 | 0.26 | 0.26 | 0.07 |
| 0.05 | 0.00 | 0.33 | 0.33 | 0.11 |
| 0.06 | 0.01 | 0.39 | 0.38 | 0.15 |
| 0.07 | 0.01 | 0.49 | 0.48 | 0.19 |
| 0.08 | 0.01 | 0.60 | 0.59 | 0.23 |
| 0.09 | 0.01 | 0.68 | 0.67 | 0.27 |
| 0.1 | 0.01 | 0.77 | 0.76 | 0.29 |
| 0.11 | 0.01 | 0.84 | 0.83 | 0.33 |
| 0.12 | 0.02 | 0.87 | 0.85 | 0.35 |
| 0.13 | 0.02 | 0.89 | 0.87 | 0.39 |

**Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## Manukau harbour

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.14 | 0.03 | 0.92 | 0.89 | 0.43 |
| 0.15 | 0.04 | 0.94 | 0.90 | 0.46 |
| 0.16 | 0.05 | 0.96 | 0.91 | 0.51 |
| 0.17 | 0.06 | 0.97 | 0.91 | 0.54 |
| 0.18 | 0.08 | 0.97 | 0.89 | 0.59 |
| 0.19 | 0.10 | 0.98 | 0.88 | 0.63 |
| 0.2 | 0.14 | 0.98 | 0.84 | 0.66 |
| 0.21 | 0.20 | 0.99 | 0.79 | 0.71 |
| 0.22 | 0.28 | 0.99 | 0.71 | 0.74 |
| 0.23 | 0.33 | 0.99 | 0.66 | 0.77 |
| 0.24 | 0.36 | 1.00 | 0.64 | 0.79 |
| 0.25 | 0.42 | 1.00 | 0.58 | 0.81 |
| 0.26 | 0.45 | 1.00 | 0.55 | 0.83 |
| 0.27 | 0.52 | 1.00 | 0.48 | 0.84 |
| 0.28 | 0.53 | 1.00 | 0.47 | 0.86 |
| 0.29 | 0.59 | 1.00 | 0.41 | 0.88 |
| 0.3 | 0.60 | 1.00 | 0.40 | 0.89 |
| 0.31 | 0.64 | 1.00 | 0.36 | 0.91 |
| 0.32 | 0.68 | 1.00 | 0.32 | 0.92 |
| 0.33 | 0.72 | 1.00 | 0.28 | 0.93 |
| 0.34 | 0.69 | 1.00 | 0.31 | 0.94 |
| 0.35 | 0.71 | 1.00 | 0.29 | 0.93 |
| 0.36 | 0.71 | 1.00 | 0.29 | 0.93 |
| 0.37 | 0.72 | 1.00 | 0.28 | 0.94 |

## NE Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.04 | 0.00 | 0.05 | 0.05 | 0.01 |
| 0.05 | 0.00 | 0.05 | 0.05 | 0.01 |
| 0.06 | 0.00 | 0.06 | 0.06 | 0.02 |
| 0.07 | 0.00 | 0.08 | 0.08 | 0.03 |
| 0.08 | 0.00 | 0.09 | 0.09 | 0.03 |
| 0.09 | 0.00 | 0.11 | 0.11 | 0.04 |

**Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion**

## NE Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.1 | 0.00 | 0.13 | 0.13 | 0.06 |
| 0.11 | 0.00 | 0.14 | 0.14 | 0.07 |
| 0.12 | 0.01 | 0.16 | 0.15 | 0.08 |
| 0.13 | 0.01 | 0.17 | 0.16 | 0.10 |
| 0.14 | 0.02 | 0.19 | 0.17 | 0.12 |
| 0.15 | 0.02 | 0.21 | 0.19 | 0.13 |
| 0.16 | 0.02 | 0.22 | 0.20 | 0.14 |
| 0.17 | 0.01 | 0.24 | 0.23 | 0.16 |
| 0.18 | 0.01 | 0.25 | 0.24 | 0.17 |
| 0.19 | 0.00 | 0.27 | 0.27 | 0.19 |
| 0.2 | 0.00 | 0.28 | 0.28 | 0.20 |
| 0.21 | 0.00 | 0.30 | 0.30 | 0.21 |
| 0.22 | 0.00 | 0.31 | 0.31 | 0.22 |
| 0.23 | 0.00 | 0.33 | 0.33 | 0.23 |
| 0.24 | 0.00 | 0.34 | 0.34 | 0.24 |
| 0.25 | 0.00 | 0.37 | 0.37 | 0.24 |
| 0.26 | 0.01 | 0.39 | 0.38 | 0.25 |
| 0.27 | 0.01 | 0.39 | 0.38 | 0.23 |
| 0.28 | 0.01 | 0.41 | 0.40 | 0.22 |
| 0.29 | 0.01 | 0.43 | 0.42 | 0.24 |
| 0.3 | 0.02 | 0.45 | 0.43 | 0.23 |
| 0.31 | 0.02 | 0.46 | 0.44 | 0.25 |
| 0.32 | 0.04 | 0.48 | 0.44 | 0.28 |
| 0.33 | 0.05 | 0.50 | 0.45 | 0.30 |
| 0.34 | 0.06 | 0.51 | 0.45 | 0.31 |
| 0.35 | 0.08 | 0.53 | 0.45 | 0.34 |
| 0.36 | 0.11 | 0.55 | 0.44 | 0.36 |
| 0.37 | 0.12 | 0.56 | 0.44 | 0.38 |
| 0.38 | 0.15 | 0.58 | 0.43 | 0.40 |
| 0.39 | 0.19 | 0.60 | 0.41 | 0.41 |
| 0.4 | 0.21 | 0.62 | 0.41 | 0.44 |
| 0.41 | 0.22 | 0.63 | 0.41 | 0.47 |
| 0.42 | 0.26 | 0.65 | 0.39 | 0.48 |
| 0.43 | 0.29 | 0.67 | 0.38 | 0.51 |
| 0.44 | 0.30 | 0.69 | 0.39 | 0.53 |
| 0.45 | 0.34 | 0.70 | 0.36 | 0.54 |

**Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## NE Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.46 | 0.36 | 0.72 | 0.36 | 0.57 |
| 0.47 | 0.38 | 0.74 | 0.36 | 0.58 |
| 0.48 | 0.40 | 0.76 | 0.36 | 0.60 |
| 0.49 | 0.44 | 0.78 | 0.34 | 0.63 |
| 0.5 | 0.46 | 0.80 | 0.34 | 0.65 |
| 0.51 | 0.48 | 0.81 | 0.33 | 0.66 |
| 0.52 | 0.51 | 0.84 | 0.33 | 0.69 |
| 0.53 | 0.51 | 0.85 | 0.34 | 0.71 |
| 0.54 | 0.54 | 0.88 | 0.34 | 0.73 |
| 0.55 | 0.57 | 0.91 | 0.34 | 0.74 |
| 0.56 | 0.59 | 0.91 | 0.32 | 0.77 |
| 0.57 | 0.62 | 0.94 | 0.32 | 0.79 |
| 0.58 | 0.64 | 0.95 | 0.31 | 0.80 |
| 0.59 | 0.65 | 0.97 | 0.32 | 0.82 |
| 0.6 | 0.68 | 0.98 | 0.30 | 0.84 |
| 0.61 | 0.70 | 0.99 | 0.29 | 0.86 |
| 0.62 | 0.71 | 0.99 | 0.28 | 0.87 |
| 0.63 | 0.74 | 1.00 | 0.26 | 0.89 |
| 0.64 | 0.76 | 1.00 | 0.24 | 0.90 |
| 0.65 | 0.78 | 1.00 | 0.22 | 0.92 |
| 0.66 | 0.79 | 1.00 | 0.21 | 0.93 |
| 0.67 | 0.81 | 1.00 | 0.19 | 0.94 |
| 0.68 | 0.82 | 1.00 | 0.18 | 0.95 |
| 0.69 | 0.83 | 1.00 | 0.17 | 0.96 |
| 0.7 | 0.84 | 1.00 | 0.16 | 0.96 |
| 0.71 | 0.86 | 1.00 | 0.14 | 0.97 |
| 0.72 | 0.88 | 1.00 | 0.12 | 0.97 |
| 0.73 | 0.84 | 1.00 | 0.16 | 0.97 |
| 0.74 | 0.87 | 1.00 | 0.13 | 0.98 |
| 0.75 | 0.89 | 1.00 | 0.11 | 0.98 |

## Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion

### NW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.07 | 0.00 | 0.26 | 0.26 | 0.06 |
| 0.08 | 0.00 | 0.22 | 0.22 | 0.05 |
| 0.09 | 0.00 | 0.24 | 0.24 | 0.07 |
| 0.1 | 0.00 | 0.34 | 0.34 | 0.07 |
| 0.11 | 0.00 | 0.34 | 0.34 | 0.08 |
| 0.12 | 0.00 | 0.47 | 0.47 | 0.11 |
| 0.13 | 0.00 | 0.53 | 0.53 | 0.13 |
| 0.14 | 0.00 | 0.65 | 0.65 | 0.16 |
| 0.15 | 0.01 | 0.75 | 0.74 | 0.21 |
| 0.16 | 0.01 | 0.80 | 0.79 | 0.24 |
| 0.17 | 0.02 | 0.89 | 0.87 | 0.31 |
| 0.18 | 0.03 | 0.92 | 0.89 | 0.35 |
| 0.19 | 0.04 | 0.96 | 0.92 | 0.43 |
| 0.2 | 0.06 | 0.97 | 0.91 | 0.49 |
| 0.21 | 0.08 | 0.97 | 0.89 | 0.54 |
| 0.22 | 0.09 | 0.98 | 0.89 | 0.59 |
| 0.23 | 0.09 | 0.98 | 0.89 | 0.64 |
| 0.24 | 0.06 | 0.99 | 0.93 | 0.66 |
| 0.25 | 0.07 | 0.99 | 0.92 | 0.68 |
| 0.26 | 0.07 | 0.99 | 0.92 | 0.68 |
| 0.27 | 0.04 | 0.99 | 0.95 | 0.66 |
| 0.28 | 0.04 | 0.99 | 0.95 | 0.64 |
| 0.29 | 0.03 | 0.99 | 0.96 | 0.61 |
| 0.3 | 0.03 | 0.99 | 0.96 | 0.58 |
| 0.31 | 0.02 | 0.98 | 0.96 | 0.55 |
| 0.32 | 0.02 | 0.98 | 0.96 | 0.52 |
| 0.33 | 0.02 | 0.99 | 0.97 | 0.50 |
| 0.34 | 0.02 | 0.98 | 0.96 | 0.45 |
| 0.35 | 0.01 | 0.98 | 0.97 | 0.42 |
| 0.36 | 0.01 | 0.98 | 0.97 | 0.40 |
| 0.37 | 0.01 | 0.99 | 0.98 | 0.34 |
| 0.38 | 0.01 | 0.98 | 0.97 | 0.27 |
| 0.39 | 0.00 | 0.97 | 0.97 | 0.24 |
| 0.4 | 0.01 | 0.99 | 0.98 | 0.18 |
| 0.41 | 0.00 | 0.98 | 0.98 | 0.15 |
| 0.42 | 0.00 | 0.94 | 0.94 | 0.16 |
| 0.43 | 0.00 | 0.94 | 0.94 | 0.16 |

**Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## SW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.01 | 0.00 | 0.04 | 0.04 | 0.01 |
| 0.02 | 0.00 | 0.08 | 0.08 | 0.02 |
| 0.03 | 0.00 | 0.09 | 0.09 | 0.02 |
| 0.04 | 0.00 | 0.12 | 0.12 | 0.03 |
| 0.05 | 0.00 | 0.15 | 0.15 | 0.05 |
| 0.06 | 0.00 | 0.19 | 0.19 | 0.07 |
| 0.07 | 0.00 | 0.22 | 0.22 | 0.09 |
| 0.08 | 0.01 | 0.25 | 0.24 | 0.12 |
| 0.09 | 0.01 | 0.28 | 0.27 | 0.15 |
| 0.1 | 0.01 | 0.33 | 0.32 | 0.17 |
| 0.11 | 0.00 | 0.38 | 0.38 | 0.19 |
| 0.12 | 0.01 | 0.41 | 0.40 | 0.22 |
| 0.13 | 0.01 | 0.45 | 0.44 | 0.23 |
| 0.14 | 0.01 | 0.48 | 0.47 | 0.25 |
| 0.15 | 0.01 | 0.52 | 0.51 | 0.27 |
| 0.16 | 0.01 | 0.55 | 0.54 | 0.28 |
| 0.17 | 0.01 | 0.60 | 0.59 | 0.30 |
| 0.18 | 0.02 | 0.64 | 0.62 | 0.33 |
| 0.19 | 0.03 | 0.71 | 0.68 | 0.36 |
| 0.2 | 0.05 | 0.74 | 0.69 | 0.40 |
| 0.21 | 0.06 | 0.78 | 0.72 | 0.43 |
| 0.22 | 0.09 | 0.82 | 0.73 | 0.47 |
| 0.23 | 0.13 | 0.86 | 0.73 | 0.51 |
| 0.24 | 0.15 | 0.88 | 0.73 | 0.55 |
| 0.25 | 0.20 | 0.92 | 0.72 | 0.58 |
| 0.26 | 0.25 | 0.94 | 0.69 | 0.62 |
| 0.27 | 0.30 | 0.97 | 0.67 | 0.66 |

**Appendix 11 cont.: West coast region QDA (Table 6) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## SW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.28 | 0.35 | 0.97 | 0.62 | 0.69 |
| 0.29 | 0.38 | 0.98 | 0.60 | 0.72 |
| 0.3 | 0.44 | 0.99 | 0.55 | 0.77 |
| 0.31 | 0.46 | 0.99 | 0.53 | 0.78 |
| 0.32 | 0.50 | 0.99 | 0.49 | 0.81 |
| 0.33 | 0.53 | 1.00 | 0.47 | 0.83 |
| 0.34 | 0.56 | 1.00 | 0.44 | 0.85 |
| 0.35 | 0.61 | 1.00 | 0.39 | 0.87 |
| 0.36 | 0.63 | 1.00 | 0.37 | 0.88 |
| 0.37 | 0.66 | 1.00 | 0.34 | 0.89 |
| 0.38 | 0.70 | 1.00 | 0.30 | 0.91 |
| 0.39 | 0.69 | 1.00 | 0.31 | 0.92 |
| 0.4 | 0.75 | 1.00 | 0.25 | 0.93 |
| 0.41 | 0.77 | 1.00 | 0.23 | 0.94 |
| 0.42 | 0.76 | 1.00 | 0.24 | 0.95 |
| 0.43 | 0.82 | 1.00 | 0.18 | 0.95 |
| 0.44 | 0.82 | 1.00 | 0.18 | 0.95 |
| 0.45 | 0.86 | 1.00 | 0.14 | 0.96 |
| 0.46 | 0.85 | 1.00 | 0.15 | 0.96 |

**Appendix 12: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## Bay of Plenty (BPLE)

| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
|---|---|---|---|---|
| | Bootstrap 95% CI for a 500 otolith sample | | | |
| 0 | 0.00 | 0.96 | 0.96 | 0.03 |
| 0.01 | 0.00 | 0.62 | 0.62 | 0.05 |
| 0.02 | 0.00 | 0.80 | 0.80 | 0.11 |
| 0.03 | 0.02 | 0.89 | 0.87 | 0.17 |
| 0.04 | 0.02 | 0.79 | 0.77 | 0.24 |
| 0.05 | 0.02 | 0.87 | 0.85 | 0.30 |
| 0.06 | 0.03 | 0.93 | 0.90 | 0.37 |
| 0.07 | 0.02 | 0.94 | 0.92 | 0.41 |
| 0.08 | 0.03 | 0.96 | 0.93 | 0.46 |
| 0.09 | 0.05 | 0.97 | 0.92 | 0.50 |
| 0.1 | 0.07 | 0.98 | 0.91 | 0.55 |
| 0.11 | 0.11 | 0.98 | 0.87 | 0.60 |
| 0.12 | 0.15 | 0.98 | 0.83 | 0.66 |
| 0.13 | 0.23 | 0.98 | 0.75 | 0.71 |
| 0.14 | 0.33 | 0.99 | 0.66 | 0.76 |
| 0.15 | 0.38 | 0.99 | 0.61 | 0.79 |
| 0.16 | 0.44 | 1.00 | 0.56 | 0.83 |
| 0.17 | 0.49 | 1.00 | 0.51 | 0.84 |
| 0.18 | 0.51 | 1.00 | 0.49 | 0.85 |
| 0.19 | 0.54 | 1.00 | 0.46 | 0.86 |
| 0.2 | 0.59 | 1.00 | 0.41 | 0.89 |
| 0.21 | 0.65 | 1.00 | 0.35 | 0.90 |
| 0.22 | 0.70 | 1.00 | 0.30 | 0.91 |
| 0.23 | 0.71 | 1.00 | 0.29 | 0.91 |
| 0.24 | 0.70 | 1.00 | 0.30 | 0.91 |
| 0.25 | 0.74 | 1.00 | 0.26 | 0.93 |
| 0.26 | 0.81 | 1.00 | 0.19 | 0.94 |
| 0.27 | 0.76 | 1.00 | 0.24 | 0.94 |

**Appendix 12 cont.: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## East Northland (ENLD)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.21 | 0.00 | 0.07 | 0.07 | 0.01 |
| 0.22 | 0.00 | 0.08 | 0.08 | 0.02 |
| 0.23 | 0.00 | 0.10 | 0.10 | 0.02 |
| 0.24 | 0.00 | 0.11 | 0.11 | 0.02 |
| 0.25 | 0.00 | 0.12 | 0.12 | 0.03 |
| 0.26 | 0.00 | 0.13 | 0.13 | 0.04 |
| 0.27 | 0.00 | 0.14 | 0.14 | 0.05 |
| 0.28 | 0.00 | 0.16 | 0.16 | 0.06 |
| 0.29 | 0.00 | 0.18 | 0.18 | 0.07 |
| 0.3 | 0.00 | 0.20 | 0.20 | 0.09 |
| 0.31 | 0.00 | 0.21 | 0.21 | 0.10 |
| 0.32 | 0.01 | 0.23 | 0.22 | 0.12 |
| 0.33 | 0.01 | 0.25 | 0.24 | 0.14 |
| 0.34 | 0.02 | 0.28 | 0.26 | 0.16 |
| 0.35 | 0.01 | 0.30 | 0.29 | 0.18 |
| 0.36 | 0.02 | 0.31 | 0.29 | 0.20 |
| 0.37 | 0.01 | 0.34 | 0.33 | 0.22 |
| 0.38 | 0.01 | 0.35 | 0.34 | 0.23 |
| 0.39 | 0.01 | 0.38 | 0.37 | 0.25 |
| 0.4 | 0.01 | 0.39 | 0.38 | 0.26 |
| 0.41 | 0.01 | 0.41 | 0.40 | 0.27 |
| 0.42 | 0.01 | 0.43 | 0.42 | 0.29 |
| 0.43 | 0.01 | 0.45 | 0.44 | 0.30 |
| 0.44 | 0.01 | 0.47 | 0.46 | 0.31 |
| 0.45 | 0.01 | 0.49 | 0.48 | 0.30 |
| 0.46 | 0.01 | 0.52 | 0.51 | 0.31 |
| 0.47 | 0.02 | 0.53 | 0.51 | 0.30 |
| 0.48 | 0.02 | 0.55 | 0.53 | 0.34 |
| 0.49 | 0.02 | 0.58 | 0.56 | 0.33 |
| 0.5 | 0.02 | 0.59 | 0.57 | 0.36 |
| 0.51 | 0.04 | 0.62 | 0.58 | 0.38 |
| 0.52 | 0.05 | 0.64 | 0.59 | 0.41 |
| 0.53 | 0.07 | 0.66 | 0.59 | 0.44 |
| 0.54 | 0.09 | 0.68 | 0.59 | 0.47 |
| 0.55 | 0.11 | 0.70 | 0.59 | 0.49 |
| 0.56 | 0.13 | 0.73 | 0.60 | 0.52 |
| 0.57 | 0.16 | 0.75 | 0.59 | 0.56 |

**Appendix 12 cont.: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## East Northland (ENLD)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.58 | 0.23 | 0.77 | 0.54 | 0.59 |
| 0.59 | 0.26 | 0.80 | 0.54 | 0.61 |
| 0.6 | 0.32 | 0.82 | 0.50 | 0.65 |
| 0.61 | 0.33 | 0.84 | 0.51 | 0.67 |
| 0.62 | 0.38 | 0.87 | 0.49 | 0.70 |
| 0.63 | 0.42 | 0.90 | 0.48 | 0.73 |
| 0.64 | 0.48 | 0.91 | 0.43 | 0.75 |
| 0.65 | 0.51 | 0.94 | 0.43 | 0.79 |
| 0.66 | 0.57 | 0.96 | 0.39 | 0.81 |
| 0.67 | 0.59 | 0.98 | 0.39 | 0.84 |
| 0.68 | 0.65 | 0.99 | 0.34 | 0.86 |
| 0.69 | 0.69 | 1.00 | 0.31 | 0.89 |
| 0.7 | 0.73 | 1.00 | 0.27 | 0.91 |
| 0.71 | 0.75 | 1.00 | 0.25 | 0.93 |
| 0.72 | 0.78 | 1.00 | 0.22 | 0.94 |
| 0.73 | 0.80 | 1.00 | 0.20 | 0.95 |
| 0.74 | 0.83 | 1.00 | 0.17 | 0.96 |
| 0.75 | 0.85 | 1.00 | 0.15 | 0.97 |
| 0.76 | 0.87 | 1.00 | 0.13 | 0.97 |
| 0.77 | 0.88 | 1.00 | 0.12 | 0.98 |
| 0.78 | 0.92 | 1.00 | 0.08 | 0.98 |

**Appendix 12 cont.: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## Hauraki Gulf (HAGU)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| Observed proportion | Lower 95 CI true predicted value | Upper 95 CI true predicted value | 95% resolution range | bootstrap median predicted value |
| 0.06 | 0.00 | 0.11 | 0.11 | 0.02 |
| 0.07 | 0.00 | 0.11 | 0.11 | 0.02 |
| 0.08 | 0.00 | 0.11 | 0.11 | 0.02 |
| 0.09 | 0.00 | 0.13 | 0.13 | 0.03 |
| 0.1 | 0.00 | 0.12 | 0.12 | 0.04 |
| 0.11 | 0.00 | 0.15 | 0.15 | 0.05 |
| 0.12 | 0.00 | 0.17 | 0.17 | 0.06 |
| 0.13 | 0.00 | 0.17 | 0.17 | 0.06 |
| 0.14 | 0.00 | 0.19 | 0.19 | 0.06 |
| 0.15 | 0.00 | 0.21 | 0.21 | 0.06 |
| 0.16 | 0.00 | 0.21 | 0.21 | 0.07 |
| 0.17 | 0.00 | 0.25 | 0.25 | 0.08 |
| 0.18 | 0.00 | 0.25 | 0.25 | 0.09 |
| 0.19 | 0.01 | 0.27 | 0.26 | 0.11 |
| 0.2 | 0.01 | 0.28 | 0.27 | 0.13 |
| 0.21 | 0.01 | 0.32 | 0.31 | 0.15 |
| 0.22 | 0.01 | 0.33 | 0.32 | 0.17 |
| 0.23 | 0.02 | 0.34 | 0.32 | 0.19 |
| 0.24 | 0.01 | 0.36 | 0.35 | 0.21 |
| 0.25 | 0.01 | 0.37 | 0.36 | 0.22 |
| 0.26 | 0.01 | 0.40 | 0.39 | 0.24 |
| 0.27 | 0.01 | 0.42 | 0.41 | 0.25 |
| 0.28 | 0.01 | 0.44 | 0.43 | 0.26 |
| 0.29 | 0.01 | 0.46 | 0.45 | 0.27 |
| 0.3 | 0.00 | 0.47 | 0.47 | 0.26 |
| 0.31 | 0.00 | 0.49 | 0.49 | 0.27 |
| 0.32 | 0.01 | 0.50 | 0.49 | 0.29 |
| 0.33 | 0.01 | 0.52 | 0.51 | 0.28 |
| 0.34 | 0.01 | 0.54 | 0.53 | 0.29 |
| 0.35 | 0.02 | 0.57 | 0.55 | 0.30 |
| 0.36 | 0.03 | 0.59 | 0.56 | 0.32 |
| 0.37 | 0.05 | 0.61 | 0.56 | 0.36 |
| 0.38 | 0.05 | 0.62 | 0.57 | 0.38 |
| 0.39 | 0.09 | 0.65 | 0.56 | 0.42 |
| 0.4 | 0.11 | 0.67 | 0.56 | 0.44 |
| 0.41 | 0.13 | 0.70 | 0.57 | 0.47 |
| 0.42 | 0.19 | 0.71 | 0.52 | 0.50 |

**Appendix 12 cont.: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## Hauraki Gulf (HAGU)

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.43 | 0.21 | 0.75 | 0.54 | 0.52 |
| 0.44 | 0.25 | 0.77 | 0.52 | 0.55 |
| 0.45 | 0.29 | 0.77 | 0.48 | 0.59 |
| 0.46 | 0.32 | 0.82 | 0.50 | 0.61 |
| 0.47 | 0.36 | 0.83 | 0.47 | 0.64 |
| 0.48 | 0.40 | 0.86 | 0.46 | 0.67 |
| 0.49 | 0.43 | 0.88 | 0.45 | 0.70 |
| 0.5 | 0.48 | 0.90 | 0.42 | 0.72 |
| 0.51 | 0.50 | 0.93 | 0.43 | 0.74 |
| 0.52 | 0.55 | 0.94 | 0.39 | 0.78 |
| 0.53 | 0.58 | 0.97 | 0.39 | 0.81 |
| 0.54 | 0.60 | 0.98 | 0.38 | 0.83 |
| 0.55 | 0.65 | 0.99 | 0.34 | 0.85 |
| 0.56 | 0.67 | 0.99 | 0.32 | 0.87 |
| 0.57 | 0.70 | 1.00 | 0.30 | 0.89 |
| 0.58 | 0.73 | 1.00 | 0.27 | 0.91 |
| 0.59 | 0.74 | 1.00 | 0.26 | 0.92 |
| 0.6 | 0.79 | 1.00 | 0.21 | 0.94 |
| 0.61 | 0.80 | 1.00 | 0.20 | 0.95 |
| 0.62 | 0.82 | 1.00 | 0.18 | 0.96 |
| 0.63 | 0.83 | 1.00 | 0.17 | 0.96 |
| 0.64 | 0.83 | 1.00 | 0.17 | 0.97 |
| 0.65 | 0.86 | 1.00 | 0.14 | 0.97 |
| 0.66 | 0.86 | 1.00 | 0.14 | 0.97 |
| 0.67 | 0.89 | 1.00 | 0.11 | 0.98 |

**Appendix 12 cont.: East coast region QDA (Table 7) true sample proportion 95% bootstrap resolution range corresponding to a given QDA "observed" proportion.**

## NW Harbours

| | Bootstrap 95% CI for a 500 otolith sample | | | |
|---|---|---|---|---|
| **Observed proportion** | **Lower 95 CI true predicted value** | **Upper 95 CI true predicted value** | **95% resolution range** | **bootstrap median predicted value** |
| 0.05 | 0.00 | 0.16 | 0.16 | 0.03 |
| 0.06 | 0.00 | 0.21 | 0.21 | 0.05 |
| 0.07 | 0.00 | 0.24 | 0.24 | 0.05 |
| 0.08 | 0.00 | 0.30 | 0.30 | 0.07 |
| 0.09 | 0.00 | 0.40 | 0.40 | 0.09 |
| 0.1 | 0.00 | 0.45 | 0.45 | 0.13 |
| 0.11 | 0.01 | 0.55 | 0.54 | 0.18 |
| 0.12 | 0.03 | 0.62 | 0.59 | 0.23 |
| 0.13 | 0.06 | 0.73 | 0.67 | 0.29 |
| 0.14 | 0.10 | 0.81 | 0.71 | 0.36 |
| 0.15 | 0.15 | 0.89 | 0.74 | 0.42 |
| 0.16 | 0.19 | 0.94 | 0.75 | 0.49 |
| 0.17 | 0.23 | 0.96 | 0.73 | 0.55 |
| 0.18 | 0.26 | 0.98 | 0.72 | 0.61 |
| 0.19 | 0.22 | 0.98 | 0.76 | 0.66 |
| 0.2 | 0.12 | 0.99 | 0.87 | 0.70 |
| 0.21 | 0.09 | 0.99 | 0.90 | 0.73 |
| 0.22 | 0.09 | 0.99 | 0.90 | 0.73 |
| 0.23 | 0.07 | 0.99 | 0.92 | 0.73 |
| 0.24 | 0.06 | 0.99 | 0.93 | 0.72 |
| 0.25 | 0.07 | 0.99 | 0.92 | 0.71 |
| 0.26 | 0.05 | 0.99 | 0.94 | 0.67 |
| 0.27 | 0.04 | 0.98 | 0.94 | 0.63 |
| 0.28 | 0.03 | 0.99 | 0.96 | 0.58 |
| 0.29 | 0.03 | 0.99 | 0.96 | 0.54 |
| 0.3 | 0.03 | 0.99 | 0.96 | 0.49 |
| 0.31 | 0.02 | 0.98 | 0.96 | 0.45 |
| 0.32 | 0.01 | 0.98 | 0.97 | 0.40 |
| 0.33 | 0.02 | 0.97 | 0.95 | 0.37 |
| 0.34 | 0.01 | 0.98 | 0.97 | 0.31 |
| 0.35 | 0.01 | 0.97 | 0.96 | 0.27 |
| 0.36 | 0.01 | 0.96 | 0.95 | 0.24 |
| 0.37 | 0.00 | 0.97 | 0.97 | 0.21 |
| 0.38 | 0.00 | 0.93 | 0.93 | 0.18 |
| 0.39 | 0.00 | 0.82 | 0.82 | 0.15 |
| 0.4 | 0.00 | 0.70 | 0.70 | 0.13 |
| 0.41 | 0.00 | 0.46 | 0.46 | 0.12 |
| 0.42 | 0.00 | 0.43 | 0.43 | 0.12 |