Beach burial of cetaceans: implications for conservation, and public health and safety

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Abstract

Every year hundreds of cetaceans strand on New Zealand beaches. Options for dealing with disposal of their carcasses are few, creating significant problems for the Department of Conservation (DOC). More often than not their carcasses are buried in beaches at or just above high water mark, near where the animals have stranded.

The primary objective of this thesis is to determine the effects of cetacean burial on beach sediments, and evaluate potential health and safety risks associated with this practice. A secondary objective of this thesis is to appraise the appropriateness of one location DOC has repeatedly transported cetacean carcasses to and buried within beach sediments, Motutapu Island in Waitemata Harbour.

The chemical effects of cetacean burial over a six-month period are reported for two sites at which animals were buried in 2008, Muriwai and Pakiri beaches; the biological effects of this burial are reported for one of these sites, Muriwai Beach, 12 months post burial. Intertidal faunal and floral inventories are provided for six sites around Motutapu Island, and these then compared and contrasted with inventories compiled from an additional 290 intertidal sites between Whangarei Heads and Tauranga Harbour, North Island East Coast, to appraise the relative uniqueness of intertidal species diversity around Motutapu Island.

At both Muriwai and Pakiri beaches, nitrogen and phosphate concentrations in surface sands changed considerably following cetacean burial, although over six months the effect was localized and elevated concentrations of these two chemicals that could be attributed to a buried carcass did not extend more than 40 m from the

site of whale burial. Deep-core profiles revealed nitrogen and phosphate concentrations at and in the immediate vicinity of cetacean burial approximately six months after burial to be markedly elevated to the level of the water table, but elevated concentrations attributable to the buried carcass were not observed greater than 25 m from the site of burial. Elevated concentrations of nitrogen and phosphates in beaches persist in surface sediments for at least six months post burial. Twelve months post cetacean burial no significant difference in species richness or abundance were apparent in intertidal communities extending along transects proximal to and some distance from the Muriwai Beach carcass; there is no evidence for any significant short-term (to 12 months) biological effects of cetacean burial in beaches.

Of those shores on Motutapu Island accessible by earth-moving equipment and large vessels capable of dealing with and transporting large cetacean carcasses, Station Bay appeared to be the most appropriate site for whale burial. However its small size, and relatively high biological value (*fairly high* species richness for comparable shores between Whangarei Heads and Tauranga) renders it an inappropriate long-term option for whale burial. Other shores on Motutapu Island host some of the highest species richness of all shores surveyed between Whangarei Heads and Tauranga Harbour, rendering them entirely inappropriate locations for burying cetaceans, over and above other variables that may influence disposal location identification (such as archaeological sites, dwellings and accessibility). Motutapu Island is not considered an appropriate location for cetacean burial within beaches. Alternative disposal strategies need to be explored for dealing with cetaceans that strand on Auckland east coast beaches.

Although burial is the most convenient and most economical strategy to dispose of cetacean carcass, especially in mass stranding events or when cetaceans are of large size, and the biological effects of this practice are not considered significant (for the one whale that could be studied), persistent enrichment of beach sediments with organic matter could result in prolonged persistence of pathogens in beaches, causing unforeseen risks to human health and safety. Recommendations are made to minimize possible threats to public following burial of cetaceans in beaches, until the potential health risks of burial are more fully understood.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed:

Ann Bui

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Introduction

Cetacean stranding events

Nearly half of the 80 known species of cetacean (whales, dolphins and porpoises) occurring world-wide occur in New Zealand waters at some stage of their life cycles, whether they be endemic to these waters or migrate through them. Some species are highly visible, such as sperm whales, southern right whales and humpback whales, but some are rarely seen or known only from individuals that have stranded on beaches, for example pygmy sperm whales (*Kogia breviceps*) or beaked whales; 22 of the 38 known species from New Zealand waters are considered to be relatively common (Hutching 2007).

New Zealand has the highest number of cetacean stranding events world wide, with the number of reported strandings having increased slightly since the introduction of Marine Mammals Act in 1987 (Brabyn 1991). Stranding events provide an unfortunate but unique opportunity to investigate aspects of the life history of cetaceans, and their role in marine ecosystems that would otherwise prove extremely difficult (Beatson & O'Shea 2009). However, stranding events also pose significant problems, particularly when it comes to disposing of their carcasses, given the health and safety concerns of possible transmission of communicable diseases between the whale, public, pets and other wild animals, and the shear size of the animals and biomass that can be involved. Recent Department of Conservation (DOC) statistics reveal almost 9,000 whales and dolphins stranded on New Zealand beaches between 1978 and 2004, of which only about a quarter could be saved (Hutching 2007); since 2004 at least a further 1,286 cetaceans have stranded on New Zealand beaches (Childerhouse 2005–2009), and assuming only one quarter of these animals could be saved this equates to 7,714 cetacean carcasses that could not be saved and have had to be disposed of since 1978 alone. Where are these carcasses today?

The most frequently stranding species are long-finned pilot whales (*Globicephala melas*), sperm whales (*Physeter macrocephalus*), pygmy sperm whales (*Kogia breviceps*), false killer whales (*Pseudorca crassidens*), common dolphins (*Delphinus delphis*), and Gray's beaked whales (*Mesoplodon grayi*), which account for 88% of the total reported stranding incidents (Hutching 2007). Three of these species, the long-finned pilot, false killer and sperm whale are known to mass strand. Mass strandings present further disposal problems, given the shear numbers of individuals and biomass that can be involved. For instance, in 1918, the world's largest mass stranding occurred at Long Beach, Chatham Islands, involving approximately 1,000 pilot whales. Hotspots of cetacean stranding in New Zealand include the Whangarei coast, Hawke Bay, Farewell Spit and Chatham Islands (Brabyn 1991); the number of stranding events, and number of individuals that have stranded, varies between years (Figure 1).

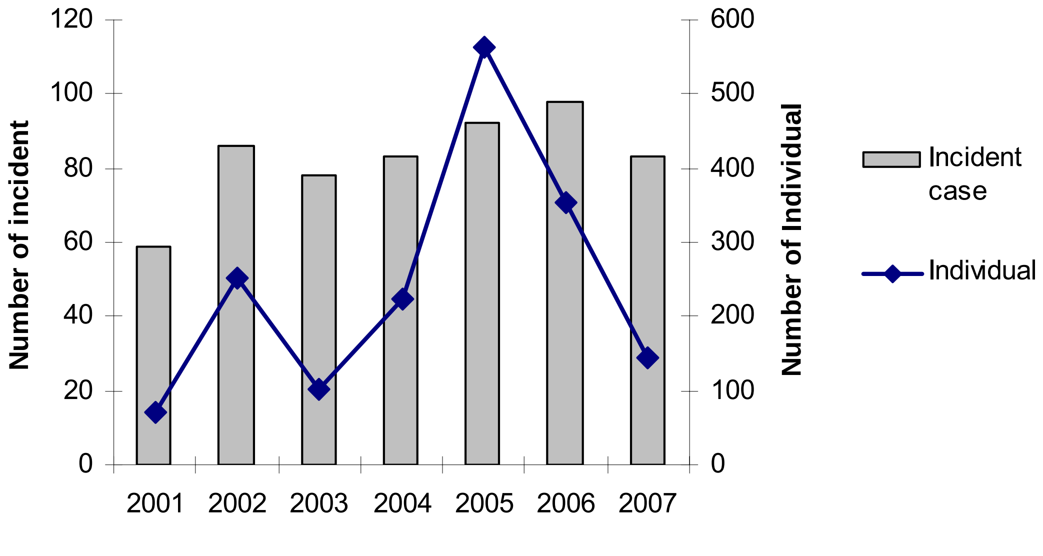

Figure 1: Summary of statistical data of whale stranding in New Zealand (modified from Childerhouse (2002–2008)

Most mass stranding events occur during the austral summer months, and may reflect increased seasonal abundance of cetaceans as they migrate into and through New Zealand waters; stranding events generally are lower during the austral winter; and herd-stranding events may have bimodal seasonality in February and October (Brabyn 1991).

Causes of mortality and potential health issue

Stranding need not prove fatal for a cetacean, although often it is, as the animal can dehydrate, its lungs can collapse under the weight of its own body when not supported by water, it can drown in the event the tide cover its blowhole, suffocate through inhalation of sand into its blowhole, or die of shock or hypothermia (Figure 2). Despite many theories having been advocated it is not well understood why stranding events occur (Geraci 1978). It is possible that a number of factors could be responsible.

Sick or injured whales often are thought to beach themselves because they are too debilitated to swim (Odell *et al*. 1980, Walsh *et al*. 1991, Bossart *et al*. 1991). Single stranding events usually are attributed to accident, parasitism or disease, and as such should be of particular concern to health authorities given the potential for transfer of communicable diseases from the cetacean to inquisitive public. Some viruses and bacteria that have been found in cetaceans, such as poxvirus (Geraci *et al*. 1979, Duignan 2000), Mycobacteria (Well *et al*. 1990,, Forshaw & Phelps 1991, Cousins *et al*. 1993) and *Vibrio* spp. (Buck *et al*. 1991, Cowan *et al*. 2001) can be transferred to humans (Cowan *et al*. 2001). *Vibrio* can produce severe or fatal infections in humans (Cowan *et al.* 2001) and was reported from hundreds of stranded Atlantic bottlenose dolphins (*Tursiops truncatus*) along the eastern United

States of America coast in 1987 (Smith 1990); it also is known to have caused death in dolphins (Fujioka *et al*. 1988), and is recognised as extremely aggressive and dangerous to humans (West 1989). Parapoxvirus can cause isolated lesions on the hands, and although not life threatening these lesions can take months to years to heal completely (Kennedy-Stoskopf 2001); most poxvirus are resistant to drying and cold temperature, in addition to common disinfectants. Mycobacteria are the source of pathogen in tuberculosis in wild animals and humans (Cowan *et al*. 2001).

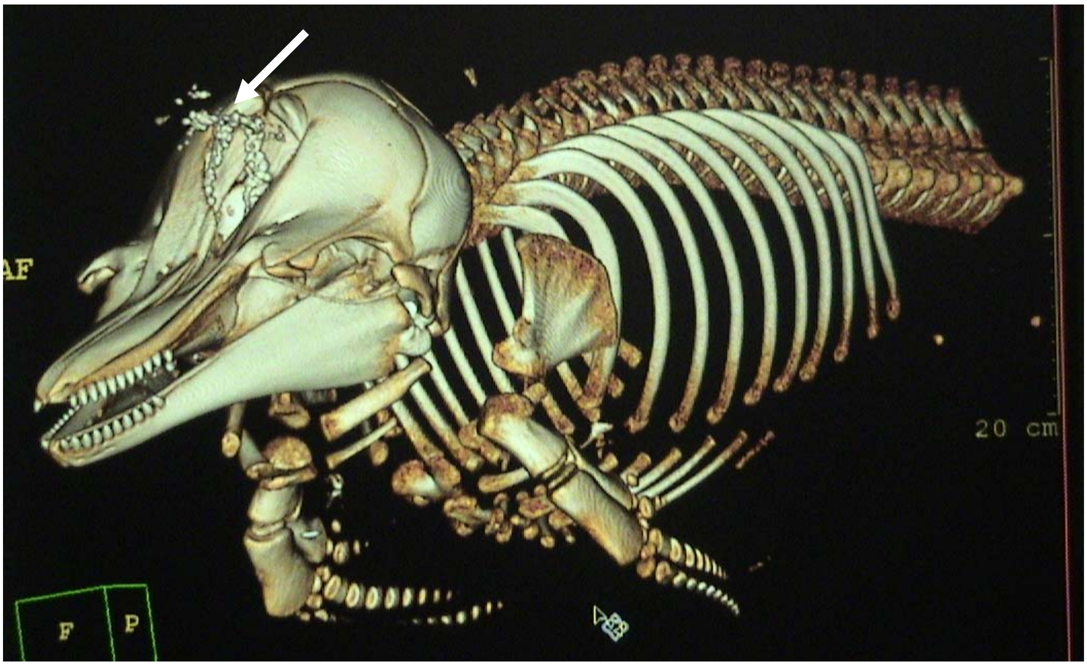

Figure 2: CT Scan of pilot whale calf, with compacted sand (arrow) in nasal passages (AUT)

Morbilliviral infection is a more common disease in mammals; 92% of long-finned pilot whales in 14 stranding events in the western Atlantic between 1982 and 1993 were morbillivirus seropositive (Duignan *et al*. 1995). Excessive infestation of parasites in the inner ear, brain or internal organs such as the kidneys, lungs, or stomach, may affect coordination or balance and cause debilitation or disorientation (Geraci 1979, Duignan 2003, Geraci & Loundsbury 1993), thus resulting in the animal beaching itself, either deliberately or accidentally.

Stranding events also have been attributed to weakness brought on by old age or difficulty giving birth, or from foraging too close to shore. Some cetacean species, such as pilot whales, live in large groups or pods with strong social bonds; when one individual in a pod strands its distress calls are thought to attract other members; as the tide recedes the entire pod can become stranded (Wood 1979, Odell *et al*. 1980). Deep-water toothed whales with strong social bonds become stranded in a group more frequently than other species (Cox 1990); often in mass-stranding events the majority of animals appear healthy (Geraci & Loundsbury 1993, Reynolds & Odell 1991). High social bonding can also account for re-stranding of cetaceans after they have been refloated.

Herd stranding of live animals appears to be most common to toothed whales (Geraci 1978), with many species involved in such stranding events using geomagnetic and echolocation cues to migrate or navigate (Kirschvink *et al.* 1985). Natural causes of stranding that could influence the cetaceans nervous or sonar systems resulting in panic and stranding could be violent electric storms and meteorological changes (Robbson & Van Bree 1971), earthquakes, and disorientation caused by geographical anomalies in the earth's magnetic field (Kirschvink *et al*. 1985, Brabyn & McLean 1992). However, several factors may be linked together, such as weather conditions and echo-distortion.

Brabyn & McLean (1992) recognise several local shoreline features common to sites of single and mass stranding events: sandy bottoms, gently sloping beaches and nearby coastal headlands. Weak echoes have been received by echosounders from sandy and otherwise gently sloping beaches compared to steep, shingle boulder beaches or rocky coasts (Hutching 2007).

Sonar has also recently been proposed as a contributor to whale strandings (Balcomb 2003), tearing tissue around ears and brain of a whale. And most recently, malnutrition also has been proposed as an additional possibly contributing factor to toothed-whale stranding in New Zealand waters (Beatson *et. al*. 2007a, b; Beatson & O'Shea 2009), as has oil spill or pesticide runoff (Dierauf & Gulland 2001). Additional causes of stranding or mortality include net entanglement, and boat or ship strike. Many beached whales have been injured and have numerous marks on their body, such as cuts on the mouth, broken jaws or teeth, or damaged flukes (personal observation).

Significance of whale meat and bone to local *iwi*

Whales are in important part of natural and cultural heritage of New Zealand (*Aotearoa*), especially Māori, who have a long association with these animals (whales are considered *tāonga* (treasured to Māori), a friend and guardian on their ancestors' canoe journeys to *Aotearoa*). Historically stranded whales provided Māori with food source high in protein, and whale's bones were fashioned into utensils and ornaments; their oil was used for polish and scent; their teeth were made into ornaments and jewelery such as *rei puta* (whale-tooth neck ornament). Whalebone, in particular the jawbones of sperm whales, were fashioned into weapons like *tewhatewha*, *patu*, *taiaha*, *hoeroa*, and other objects like *heru* (combs), *tokotoko* (walking sticks), and *hei tiki* (neck ornaments) (Hutching 2007). Today whale bone is collected by *iwi* and provided to museums, traded, gifted or exchanged under the control of Marine Mammals Protection Act (1978).

Figure 3: Sperm whale bone recovery exercise, Taupo Bay, Northland, 02/2008 (AUT)

Europeans brought commercial whaling to New Zealand in the later 18th century, and many Māori became involved in this new industry; 40% of whalers were in fact Māori (Hutching 2007). Whaling continued in New Zealand until 1965, when the last whaling station was closed, after the International Whaling Commission prohibited humpback whaling throughout the Southern Hemisphere (Hutching 2007).

Although *iwi* whalebone recovery operations now are relatively commonplace in Northland, New Zealand, given the number of stranding events, sizes and numbers of individuals that strand, and the fact that not all whales have bone appropriate for recovery purposes, the disposal of unwanted cetacean carcasses, and the flesh from whales post *iwi* whalebone recovery, presents significant financial and logistical problems for DOC.

Figure 4: Typical stranding events, sperm whales (left, top to bottom, Gray's beaked whales (right, top, bottom) (AUT)

Figure 5: Mature male sperm whale, Palliser Bay, 03/2007, jawbone recovered by *iwi*, with digger assisting in opening abdominal cavity to access stomach contents (AUT)

Figure 6: Matauri Bay, Northland East Coast, 02/2008, burial site in dunes at high-water mark for two Gray's beaked whales (note water table in pit) (AUT)

Figure 7: Whale disposal options: *top left*, left on beach; *top right*, land (coastal) burial; *middle left*, discarded in offal pond; *bottom left*, burial in sand dune; *bottom right*, removal for burial at an alternative, less-populated beach (AUT)

Carcass disposal

Options for disposal of unwanted cetaceans, or their flensed remains post whale-bone recovery are few, although those available for small cetaceans are exceed those for larger animals. Basically the most financially viable disposal options are to leave the animals on beaches for them to decompose naturally; remove them from beaches and dispose of them at sea; bury them within beaches or adjacent land; or attempt to break the carcass into manageable pieces to facilitate manual removal or removal by scavengers, such as has been trialed with explosives.

Option 1: leaving carcasses on beaches

The DOC Marine Mammal Stranding Contingency Plan (2007) allows for cetacean carcasses to be left on beaches in the event they pose no risk to public health and will have no effect on residents. This option is usually followed when a carcass strands on a remote beach that is inaccessible to vehicles, and is away from any residential properties. The carcass left on the surface will decompose quickly (Dierauf & Frances 2001, Geraci & Lounsbury 1993), aided by the weather, tides and activities of scavengers; it is recommended to remove the tusks and teeth (if present) to protect the carcass from souvenir hunters, and to incise the abdomen so as to avoid eventual explosion caused by gas building up within the abdominal cavity during decay (Geraci & Lounsbury 1993).

Option 2: burial

Beach burial of cetaceans is currently the primary means of cetacean carcass disposal, especially in densely populated areas, or areas used extensively for recreational activities. Most beached whales are buried within the beach near where they strand, usually at high water (Figure 6). Others are towed from the stranding site and buried in sand dunes further alongshore or at another location, or even towed onto land and buried there. Depending on the size of a carcass, the number of individuals involved in any stranding event, burial location and availability of equipment, carcasses could be buried anywhere from 1 to 6 m depth.

Option 3: sea-disposal

Sea disposal requires boat access to the site of a stranding, and attaching ropes or wires to the carcass to haul it off the beach, then to tow the carcass to sea where it can be eventually sunk or released. Rendering whale carcass back to sea is problematic as bloated carcasses tend to float and may re-beach themselves presenting costly secondary disposal costs (Dierauf & Frances 2001); large floating carcasses could also pose serious navigational hazards. A carcass to be disposed of at sea should have the abdominal cavity opened, or be moved far enough offshore and have enough ballast to sink it so as to avoid its re-stranding (Geraci & Lounsbury 1993).

Sea disposal requires a level of infrastructure and planning (availability of sufficient ballast, appropriate sized and powered vessels, and sufficient rope, chain or wire, and labour) that might not prove viable in the event of a mass stranding, stranding in an otherwise remote location, or stranding, for instance, off an Auckland west coast beach that cannot be safely accessed by an appropriately sized vessel. For instance, a 53-foot fin whale was towed offshore and sunk in November 2002 at San Juans Island, Washington, US; it required a 32 m barge and nine tons of concrete highway barrier to sink it (Hornung 2002).

Whales die at sea, where their carcasses naturally, eventually sink to the sea bed, providing a massive source of organic matter to the deep-sea floor. It has been reported that whale carcasses provide food and habitat for up to 407 species (Smith & Baco 2003); 21 macrofaunal species are even thought to be whale-fall specialists (Smith & Baco 2003). Organic carbon contained in a 40-ton whale has been calculated to be the equivalent of that typically sinking from the euphotic zone to a hectare of abyssal sea floor over a 100─200 year period (Smith & Demopoulos 2003). Almost 90% of soft tissues were removed from a 5-ton carcass in 4 months post sea-disposal, and in 18 months for a 35-ton carcass (Smith *et al*. 2002), with scavengers (e.g., hagfishes, sharks, macrourids, amphipods and copepods) removing tissue from a carcass at a rate of 40–60kg per day (Smith & Baco 2003). An unconventional variant of this form of disposal was that for a Gray's beaked whale on Motutapu Island, Hauraki Gulf, towed onto land and disposed in an offal pond on a farm, alongside a dead cow and other extraneous matter (Figure 7).

Option 4: carcass disintegration

A half-ton of explosives were used in an attempt to dispose of a rotting 14 m sperm whale in United States in 1970 (Exploding whale, n.d. and Geraci & Lounsbury 1993). The intention had been to disintegrate the whale, breaking it up into small-enough pieces that would be relatively easy for scavengers to remove, or for the tide to wash away. Although a spectacular sight, explosives proved to be ineffective as only a small part of the whale was destroyed, leaving the greatest proportion on the beach to dispose of in a more conventional manner. Additionally, this method is considered less acceptable because of huge damage to soft tissues, damage to surrounding vehicles, excessive noise, and human safety (Dierauf & Frances 2001).

Option 5: Incineration/Biohazard disposal

Incineration has been suggested for disposal for small carcasses, but is not recommended given the high cost associated with this option (Geraci & Lounsbury 1993). Biohazard disposal is equally expensive, if not more so.

Despite the second option, that of beach burial proximal to the site of stranding, being the most frequently adopted approach for disposal of cetaceans that strand on

New Zealand beaches, no research on the effect of cetacean burial in beach sediments has been undertaken nationally, or to the best of my knowledge, internationally. Remember, 7,714 cetacean carcasses may have been buried in New Zealand beaches since 1978 alone!

Mammalian decomposition

Given the absence of any information on the effects of cetacean burial in beach sediments, forensic literature provides a valuable source of information available on mammalian decomposition rates, and potential effects that these could have on the surrounding landscape.

Immediately post mortem, fluids in an animal's carcass begin to decompose, caused by two main factors: breaking down of tissues by the bodies own internal chemicals and enzymes, and breakdown of tissues by bacteria. Products of this decomposition include small nitrogenous compounds, fats, ammonia gas, nitrates, nitrites, phosphates, bacteria and other carbohydrate matter. The decomposition process has six main stages: 1) Fresh, 2) Bloated, 3) Active Decay, 4) Advanced Decay, 5) Dry, and 6) Remains) (Carter *et al*. 2006).

Fresh stages of decomposition are associated with cessation of the heart and depletion of internal oxygen; a lack of oxygen inhibits aerobic metabolism, causing cellular breakdown by enzymatic digestion (autolysis). The depletion of internal oxygen also creates an ideal environment for anaerobic micro-organisms (e.g. the bacteria *Clostridium*, *Bacteroides*) originating from within the gastrointestinal tract and respiratory system to proliferate. After the onset of anaerobiosis, microorganisms transform carbohydrates, lipids and proteins into organic acids (e.g. propionic acid, lactic acid) and gases (e.g. methane, hydrogen sulphide) (Carter *et al*. 2006).

During the *Bloated* stage, internal pressure from gas accumulation forces fluids to escape from cadaveric orifices (mouth, nose, anus), and these then flow into the soil, likely causing a localised flush of microbial biomass, shift in soil faunal communities, C-mineralisation (CO_2–C evolution), and increase in soil-nutrient status; this then feeds more oxygen back into the cadaver and exposes more surface area for the establishment of fly larvae and aerobic microbial activity.

Active Decay is characterised by rapid loss of cadaver mass, caused by peak maggot activity, and further, substantial release of cadaveric fluids into the soil via skin ruptures and natural orifices.

Advanced Decay is determined by the size of the cadaver, the extent of maggot mass, temperature and soil texture. A summer temperature of 25^{o}C would result in the onset of *Advanced Decay* after 16 days while winter temperature of 5^{o}C would result in an onset after 80 days (Carter *et al.* 2006). A cadaver decomposition island (CDI), a visible zone of dead plant material around the cadaver, is formed during this stage. A high quality resource is associated with a significant amount of available carbon, high level of microbial activity and rapid rate of nutrient release. *Advanced Decay* is also associated with a significant increase in the concentration of soil nitrogen (Carter *et al*. 2006).

The distinction between *Advanced Decay* to *Dry* to *Remains* stage is difficult to draw. Increased plant growth around the edge of the CDI has been proposed as an indicator of the *Dry* stage, while increased plant growth within a CDI might indicate the *Remains* stage (Carter *et al*. 2006).

Decomposition rate is affected by many factors, such as moisture, temperature, exposure to air or the availability of oxygen, depth of burial, microorganisms, soil pH, humidity, enzymes, trauma or wounds, scavengers, and the size and weight of a carcass (Judah 2008). A basic guide (Casper's Law) to determine the rate of decomposition is that when a carcass is exposed to air the decomposition process occurs twice as fast as it does when immersed in water, and eight times faster than if the carcass is buried (Judah 2008).

Burial of a cadaver in soil restricts access to most insects and scavengers, resulting in significantly reduced rates of decomposition than if the carcass were left on the surface; scavengers and insects may eat or otherwise remove large amounts of flesh in relatively short period of time.

Coarse-textured (sandy) soils with low moisture content frequently promote carcass desiccation. This phenomenon is related to the diffusion of gases through the soil matrix, with coarse-textured soils associated with a high rate of gas diffusivity, enabling gases and moisture to move relatively rapidly through the soil matrix. Hydrolytic enzymes associated with the cycling of carbon and nutrients are retarded by low moisture content, so coarse-textured soils that rapidly lose moisture promote desiccation; desiccation can inhibit decomposition and result in the natural preservation of a cadaver.

The burial of a cadaver in a wet, fine-textured soil can result in a decreased decomposition rate because the rate at which oxygen is exchanged with CO_2 might not be sufficient to meet aerobic microbial demand. Thus, reducing conditions are established whereby anaerobic micro-organisms dominate decomposition. These organisms are less efficient decomposers than aerobes.

In extremely dry or cold conditions the normal decomposition process is halted, as moisture and temperature control both enzymes and bacterial activity. pH also affects the growth of major aerobic and anaerobic spoilage bacteria, and could inhibit or accelerate the decomposition process; acidic soils can also promote the leaching of phosphorus from bone.

Whales as cadavers

Very limited information is available on decomposition rates of cetaceans, with the exception of ecological studies that have monitored community succession on sunken whale carcasses (Braby *et al*. 2007, Goffredi *et al*. 2004, Rouse *et a*l. 2004).

Mature whale size can vary from a few metres, the likes of pygmy sperm whales, porpoises or dolphins, to more than 30 m, in the case of the blue whale. Weight can be very difficult to measure (Cox 1990, Ward 2009) and is usually only estimated, ranging from several hundred kilograms (pygmy sperm whale) to approximately 100 tons (blue whale, *Balaenoptera musculus*) (Perrin *et al*. 2008).

The time required for a whale carcass to reach a "*Remains"* stage is not known, and will vary according many factors, such as burial depth, temperature, substratum type, and pH. Muscle, blood and fat would decompose into organic matter, and a significant mass of organic matter then is likely to sink through the sediments and enter the water table, eventually, in the case of beach burial, leaching through the beach into the sea. The greater the whale mass the greater the nutrient input into the beach, and likely the longer it would take to reach "*Remains*" stage.

Nitrogen is an essential part of amino acids, and phosphorus is found bound in DNA and RNA in all living organisms. Whale meat is high in protein, made of amino acids. When a whale carcass decomposes, its protein-rich muscles, blood and fat would decompose into organic matter. These organic matters then break down and produce nitrogen and phosphate. These elements are also the main components of fertilizer; a 1-tonne carcass could produce the equivalent of 120 kg of fertilizer, that potentially could promote plant and other microorganism development (Carter *et al*. 2006); Carter *et al*. (2006) calculated a 5 ton cadaver could provide sufficient fertilizer to cover a square km of terrestrial ecosystem for one year.

Nitrogen is an essential component of proteins, nucleic acids and other cellular constituents. In aquatic systems, eutrophication is the result of increased N loading, causing coastal algal blooms, fish kills and increased turbidity. Phosphorus, a very reactive element that does not exist in pure elemental form, is essential for plants and animals, in the form of phosphate ions; is also necessary for development of tissue such as teeth and bone. Naturally occurring sources of nitrogen and phosphates in beach sediments could include beach-cast seaweed, or animals, such as dead birds, seals, beach-cast fish, and pelagic organisms the likes of *Lepas* barnacles on driftwood, flotsam and jetsam (Figures 8, 9).

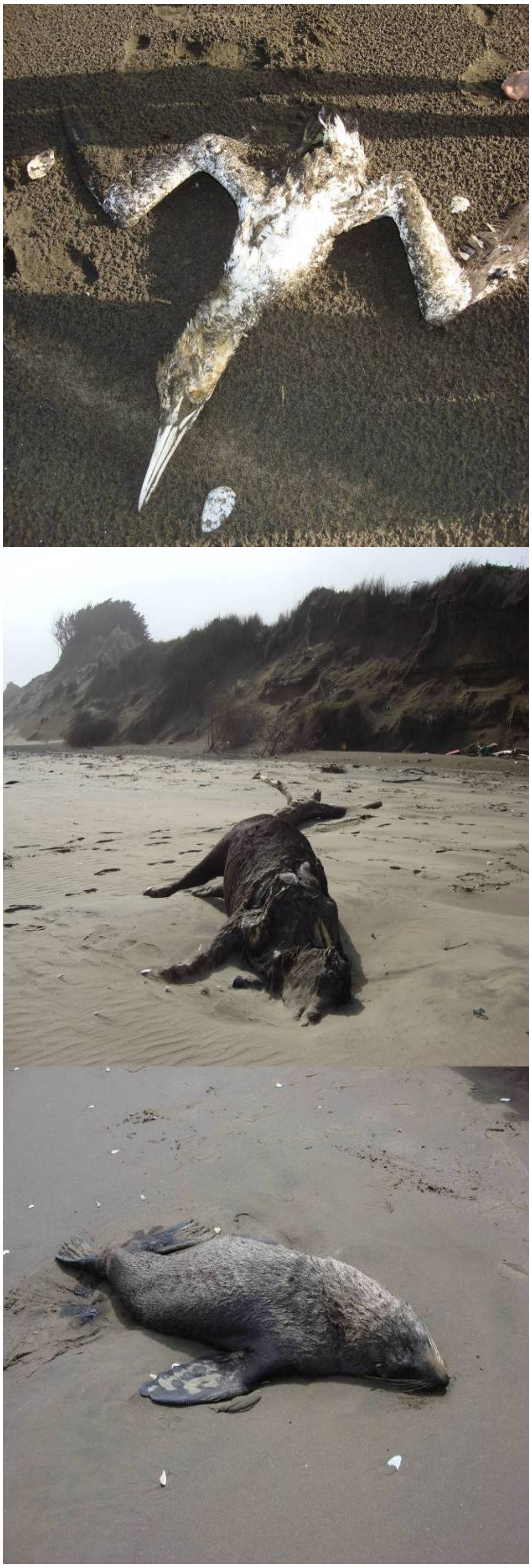

Figure 8: Dead gannet (*Morus serrator*), cow, and fur seal (*Arctocephalus forsteri*), Muriwai Beach, 08/2007 respectively

Figure 9: Drift kelp (*Durvillea*), pellet and associated encrusting barnacles (*Lepas anatifera*) cast ashore, Muriwai Beach, 08/2007 respectively

Significance of this thesis

No environmental impact appraisal has been undertaken to determine the effects of cetacean burial on coastal flora and fauna, nationally or internationally. It is possible that burial of these cetaceans could elevate nutrient and pathogen levels in beach sediments, causing persistent, deleterious effects on the distribution, abundance and diversity of coastal invertebrates, and presenting health and safety risks to the unsuspecting public. However, to an extent, as cetacean stranding is a natural phenomenon, even though the frequency of these events might be exacerbated by anthropogenic disturbance, the fauna and flora of coasts could be naturally subject to elevated levels of organic enrichment, and perhaps even depend on it; the same could apply to pathogens. This is especially true of those areas that are hotspots of cetacean stranding, such as Hawkes Bay, Farewell Spit, and the coastal waters around Whangarei.

With increased coastal development, four-wheel drive access to beaches, and recreational activities at locations that were once considered remote, stranding is likely to impact on more people than would have been the case decades earlier. Should a stranding occur on an Auckland east coast beach, for example Takapuna Beach, then burial of such a large animal in this beach would not be favourably received by myriad visitors that frequent this shore daily.

Motutapu Island is a 1,509 hectare island, located in the Waitemata Harbour, adjoining Rangitoto Island (Motutapu Restoration Trust 2003). The island has important wildlife, conservation, scientific and historic vales, and these provide a wide range of recreation opportunities. This island was incorporated in the Hauraki Gulf Maritime Park in 1967, and has been administered by DOC since 1989 (Kayes *et al*. 1992). Any activity or land modification requires consultation with DOC (Planning 2003). There are no permanent residents on Motutapu Island.

Since 2007 DOC has buried two Bryde's whale carcasses (*Balaenoptera edeni*), each approximately 11 m length, found dead in Waitemata Harbour at Station Bay, Motutapu Island (Karl McLeod, DOC [Auckland Conservancy], pers com 2007); in 1994 a pygmy sperm whale also was buried there. This bay has both vehicle access suitable for tractors and diggers, and is large and deep enough for large boat access, especially that required to tow a substantial whale carcass.

DOC selected Motutapu Island as the location at which to dispose of cetacean carcasses that 'presented problems' (e.g., washed ashore, or would have (e.g., dead following ship-strike)) in Hauraki Gulf, as few alternatives existed given the extent of residential development on most mainland Auckland beaches (McLeod pers com). As DOC manages Motutapu Island, had staff and heavy machinery on the island, did not require land-owner consent to bury carcasses, no permanent residents lived on the island, and it was situated relatively close to Auckland, it was identified as a convenient and relatively economical location at which carcasses could be towed to and disposed of in beach sediments. As for any other site of whale burial, no environmental impact appraisal has been undertaken on Motutapu Island to determine what the effects this activity might be on the coastal flora and fauna.

Thus, the objectives of this thesis were established:

1) To determine the physical and biological effects of cetacean burial on beach sediments.

2) To appraise the appropriateness of Motutapu Island as a site at which cetaceans that ‘presented problems’ on the east coast of Auckland, particularly within Waitemata Harbour, could be buried.

To achieve the objectives of this study it was originally proposed that surrogates for whales, nine comparably sized pigs, would be buried in beach sediments at various depths, three each left on the surface, and three each buried at 1 m and 2 m depth at some remote location on Muriwai Beach (southern Kaipara Heads, west coast of Auckland). This proposed research required a coastal permit, and it was extremely likely, given the shear number of recreational users at even the most remote of locations along this beach that any carcass left on the surface would not have been tampered with by public or run over by off-road vehicles (see Figure 10, a Wednesday afternoon, one tidal cycle, for vehicle tracks along Muriwai Beach).

The intention had been to compare rates of decomposition of these nine pigs over time, then to exhume the bodies at the completion of the experiment. However, immediately prior to commencing this research programme two whales stranded within a short space of time, and this presented an ideal opportunity to study decomposition of these animals, albeit in a non-replicated manner. Unfortunately neither carcass could be exhumed upon completion of this research.

Figure 10: Vehicular tracks, Muriwai Beach, 08/2007 (AUT)

Methods

Study sites

Three survey sites are reported on in this thesis, Muriwai Beach on the Auckland west coast, Pakiri Beach on the Auckland east coast, and Motutapu Island, in Waitemata Harbour (Figure 11).

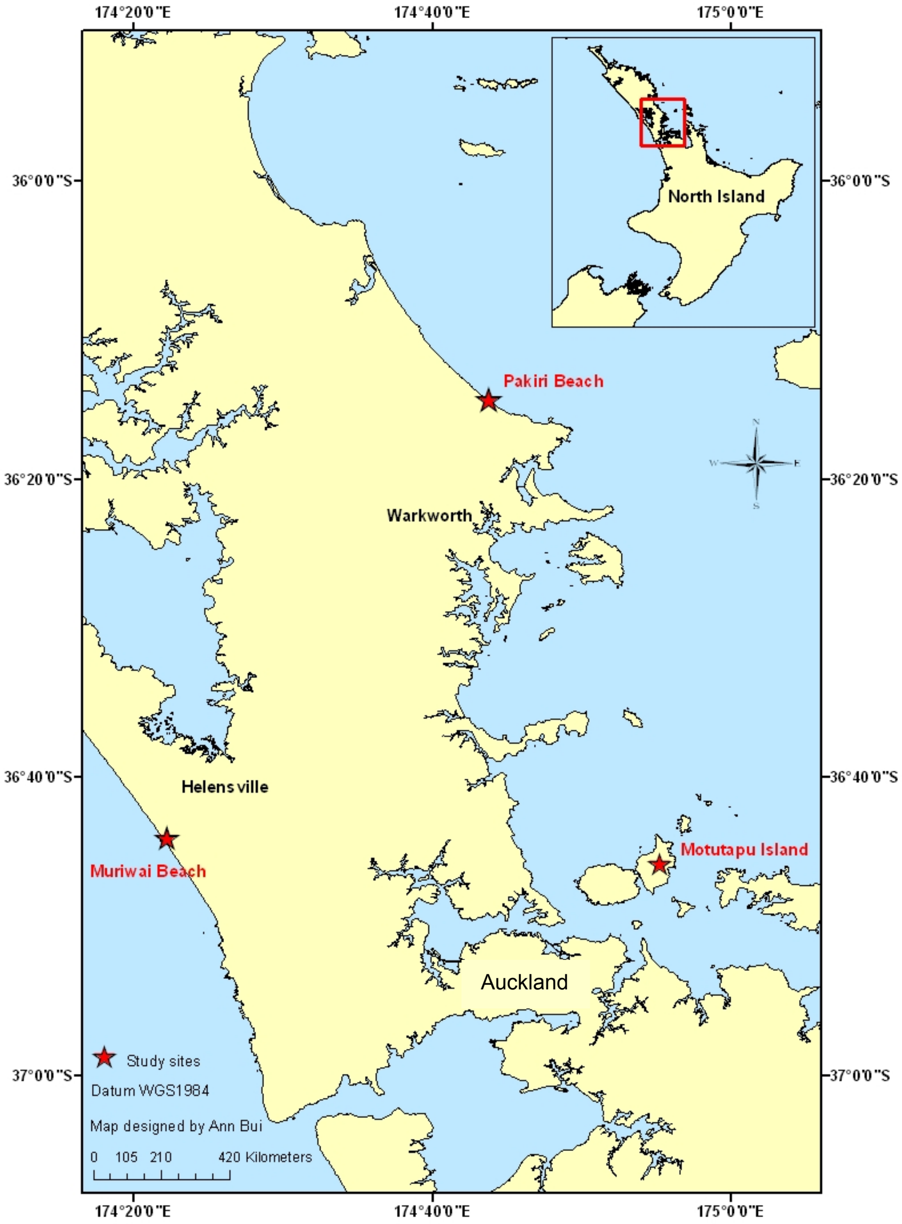

Figure 11: Locations of survey sites reported in this thesis

Pakiri Beach

Pakiri beach, on the east coast of Auckland, is the only exposed surf beach free of any major residential development. This 52 hectare piece of land includes 900 m of white sandy coastal foreshore and stands of mature coastal pohutukawa trees along the dunes; it was purchased by the ARC in late 2005, forming its 25th regional park (Auckland Regional Council 2). It has regional significance as a wild and scenic coastline with extensive sand dunes and dune lakes that could be use for beach activities such as swimming, fishing, surfing, picnicking, and walking.

A female Gray's beaked whale (*Mesoplodon grayi*, 4.65 m length) stranded at Sandspit on 27 February 2008 and was subsequently moved by road on a trailer to Pakiri Beach for whalebone recovery and burial (Figure 12). The selected burial site was some distance from high water, in a depression between two dunes.

The carcass was completely flensed, and all bones were buried separately from flesh in adjacent pits, manually excavated to approximately 1 m depth, with the two pits separated by approximately 2 m (Figure 13). Stomach contents of this whale were collected, but are not reported herein.

As is typical of any stranding event, there was no time to undertake any pre-burial impact appraisal at this site; site selection was determined by mutual agreement between *iwi* and DOC personnel.

Figure 12: Gray's beaked whale being transported to Pakiri Beach by trailer, 02/2008 (AUT)

Figure 13: Manual excavation of trench to accommodate Gray's beaked whale carcass, Pakiri Beach, 02/2008 (AUT)

Muriwai Beach

This surf beach extends approximately 60 km along the west coast of Auckland. The intertidal platform extends over 200 m towards low water, the sands are black (ironsand), and the foreshore comprises rolling dunes. The beach is easily accessible by off-road and 4-wheel drive vehicles, and is used extensively by recreational fishers, surfers, swimmers, bathers, paragliders, horse riders, and off-road vehicles and bikes. Sand dunes at Muriwai are fragile and eroding (Auckland Regional Council 1), a problem exacerbated by irresponsible off-road vehicle use in the dunes.

A male Orca (killer whale, *Orcinus orca*, 6.06 m length) was buried at Muriwai Beach, 7 km north of Okiritoto stream on 19 March 2008. The whale had been earlier seen dead, offshore, a week previously by a fisherman. The *Orca* was moved by bulldozer approximately 50 m from the site at which it stranded to a point several metres above high water. What teeth remained in the carcass were removed by *iwi*, although the jaw had been vandalized and many teeth extracted. The abdomen was incised to recover the stomach contents; this incision also enabled gases within the abdomen to escape during the subsequent decomposition post burial; no further bone recovery was attempted, so the whale was basically intact at the time of burial. A bulldozer then excavated and pushed the carcass into a trench approximately 2 m in depth, then covered the carcass with the excavated sand.

Figure 14: Abdomen of Orca being opened to enable access to stomach contents, Muriwai Beach, 03/2008 (AUT)

Figure 15: Orca being buried at high water, Muriwai Beach, 03/2008 (AUT)

Beach surveys

The two main objectives of this thesis were to:

1. Determine the physical and biological effects of cetacean burial on beach sediments.
2. Appraise the appropriateness of Motutapu Island as a site at which cetaceans that came ashore on the east coast of Auckland, particularly within Waitemata Harbour, could be buried.

To determine the physical effects of cetacean burial on beach sediments, surface sands were collected at regular intervals along transects extending from the centre of each site cetacean burial. Surface sands were selected as this is the interface that the public is most likely to be exposed to. Sampling methodology was influenced by the topography of burial sites, and by restrictions imposed by tidal height on each of the survey locations. As such, the sampling strategy for the two burial sites differed, although the basic design was one of sampling along transects at regular intervals, radiating away from the point-source of impact (the site of whale burial).

Surface sediment sampling

Surface sands were collected from each site, Pakiri and Muriwai beaches, prior to any bone recovery or incision into the abdomen of any animal, so as not to contaminate sands prior to determination of background levels of nitrogen and phosphate (Table 1). Weather and tidal conditions (vehicle access) prevented sampling at precisely one monthly intervals.

At Muriwai Beach, five transects ran from the centre of the site of whale burial down the shore at angle 45^o, 60^o, 90^o, 120^o and 135^o parallel to high water mark, each extending towards low water (Figure 16). The number of sand samples collected on each sampling date depended on weather and tidal cycles (Table 1); a single sample was collected at each site by plastic trowel from a depth of 20 cm, with individual samples collected at 5 m intervals along each transect during each sampling event. Samples were placed into labeled plastic bags, transported back to AUT and frozen within three hours (transit time) of collection.

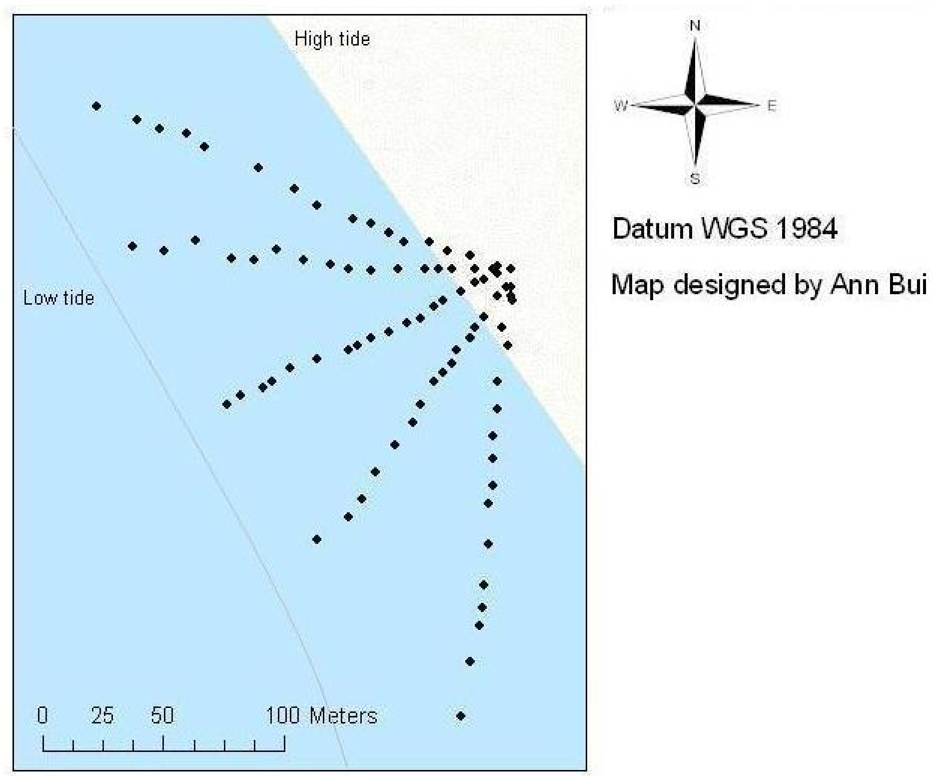

Figure 16: Radiating survey design for collection of sand samples, Muriwai Beach

At Pakiri Beach, given the whale was buried in a depression between two large dunes, and shoreward of the burial site the dunes were covered in dense vegetation, three transects were run from the burial site, one either side of it and parallel to the coast, and one perpendicular to the coast (Figure 17). Sand samples at each site were similarly collected by plastic trowel from a depth of 20 cm, with individual samples collected at 3 m intervals along each transect during each sampling event; GPS coordinates for each sample were taken. Samples were placed into labeled plastic bags, transported back to AUT and frozen within four hours (transit time) of collection.

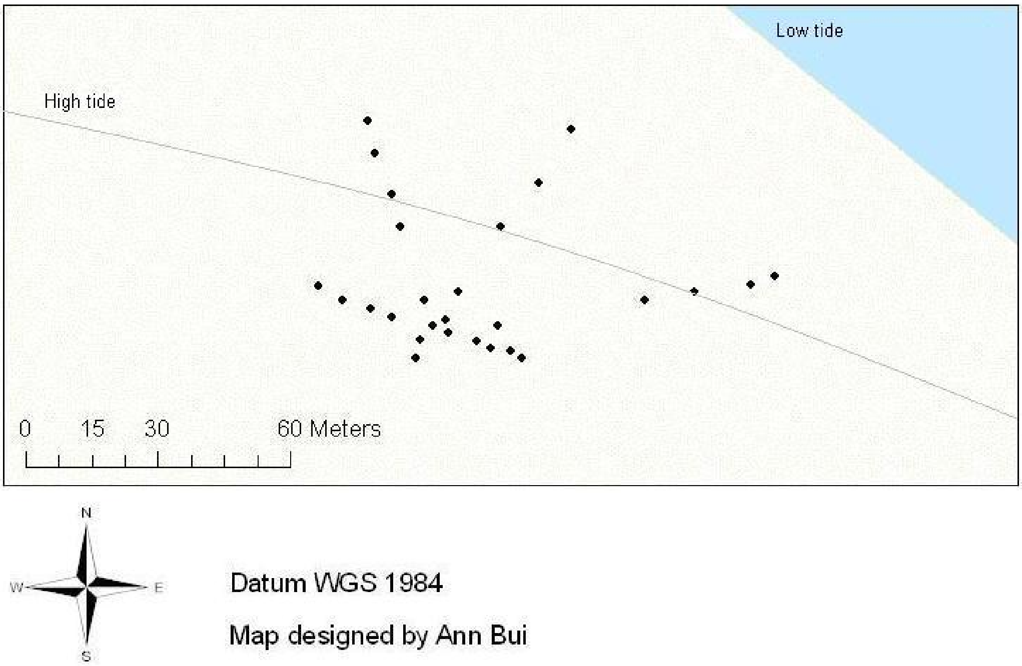

Figure 17: Radiating survey design for collection of sand samples, Pakiri Beach

Table 1: Survey dates, locations and activities

Date	Location	Activity	No of samples
29/02/2008	Pakiri	Gray's beaked whale burial and surface sampling (week 0)	23
17/03/2008	Pakiri	Surface sampling (week 2.5)	23
20/03/2008	Muriwai	Orca burial and surface sampling (week 0)	18
31/03/2008	Muriwai	Surface sampling (week 1.5)	54
11/04/2008	Pakiri	Surface sampling (week 6)	25
21/04/2008	Muriwai	Surface sampling (week 4.5)	71
27/05/2008	Pakiri	Surface sampling (week 12)	31
03/06/2008	Muriwai	Surface sampling (week 10.5)	64
25/07/2008	Pakiri	Surface sampling (week 17)	26
17/09//2008	Muriwai	Surface sampling (week 26)	85

Deep-core sampling

An AMS soil sampling kit enabled samples to be collected to subsurface depths of 4 m in and around sites of cetacean burial; this equipment was not available for the first five surveys of any site of whale burial. The manually operated corer comprises series of stainless steel extensions, a handle, and a collecting auger. The auger was screwed into the sand surface and at pre-marked depths of 0.5 m along the extensions a sample was taken; samples were collected to the water table at each site (Figure 18), with the actual level determined by theodolite at 1 m vertical intervals from high water. Samples were placed into labeled plastic bags, returned to AUT and frozen within four hours of collection.

Because of differences in beach topography and tidal reach, the deep-core sampling strategy differed for Muriwai and Pakiri Beaches. At Muriwai Beach deep-core samples were collected every 0.5 m from the surface above the whale, to a maximum depth of approximately 4 m (the water table at the highest point on the shore), along one transect perpendicular to the tide line and extending down the shore; at Pakiri, deep-core samples were collected every 0.5 m from the surface above the whale to a maximum depth of approximately 2 m (the water table at the highest point on the shore), along a transect running parallel to the shore. The water table was considered reached when returned sand cores were suddenly, effectively saturated with water.

Figure 18: Operation of deep core and theodolite at Muriwai Beach (08/2008): *top left*, deep core operation; *top right*, view down bore; *bottom left*, removal of core sample from ~ 4 m depth; *bottom right*, theodolite and extraneous debris on beach (AUT)

Motutapu Island intertidal sediments

Part of the second main objective of this research entailed collection of surface sand samples from Motutapu Island beaches to determine background levels of nitrogen and phosphates in these sediments.

Sand samples were collected from six beaches on Motutapu Island, in accordance with Table 2, and Figure 19. Beaches were selected on grounds of sediment type, road and vessel access, land use, and proximity (or lack thereof) to dwellings. At each beach, three surface sand samples were collected from the intertidal zone between high and mid-tide levels. Samples were placed into labeled plastic bags, transported back to AUT and frozen. These samples were analysed for total nitrogen and phosphate in accordance with the techniques cited over page for intertidal sands at Muriwai and Pakiri Beaches. GIS coordinates were recorded at each sample site.

Table 2: Beaches on Motutapu Island surveyed for nitrogen and phosphate concentrations

Date	**Location**	**# samples**
07/04/2008	Islington Bay	3
07/04/2008	Home Bay	3
08/04/2008	Mullet Bay	3
08/04/2008	Waikarapupu Bay	3
09/04/2008	Station Bay	3
09/04/2008	Near Otahuhu Point	3

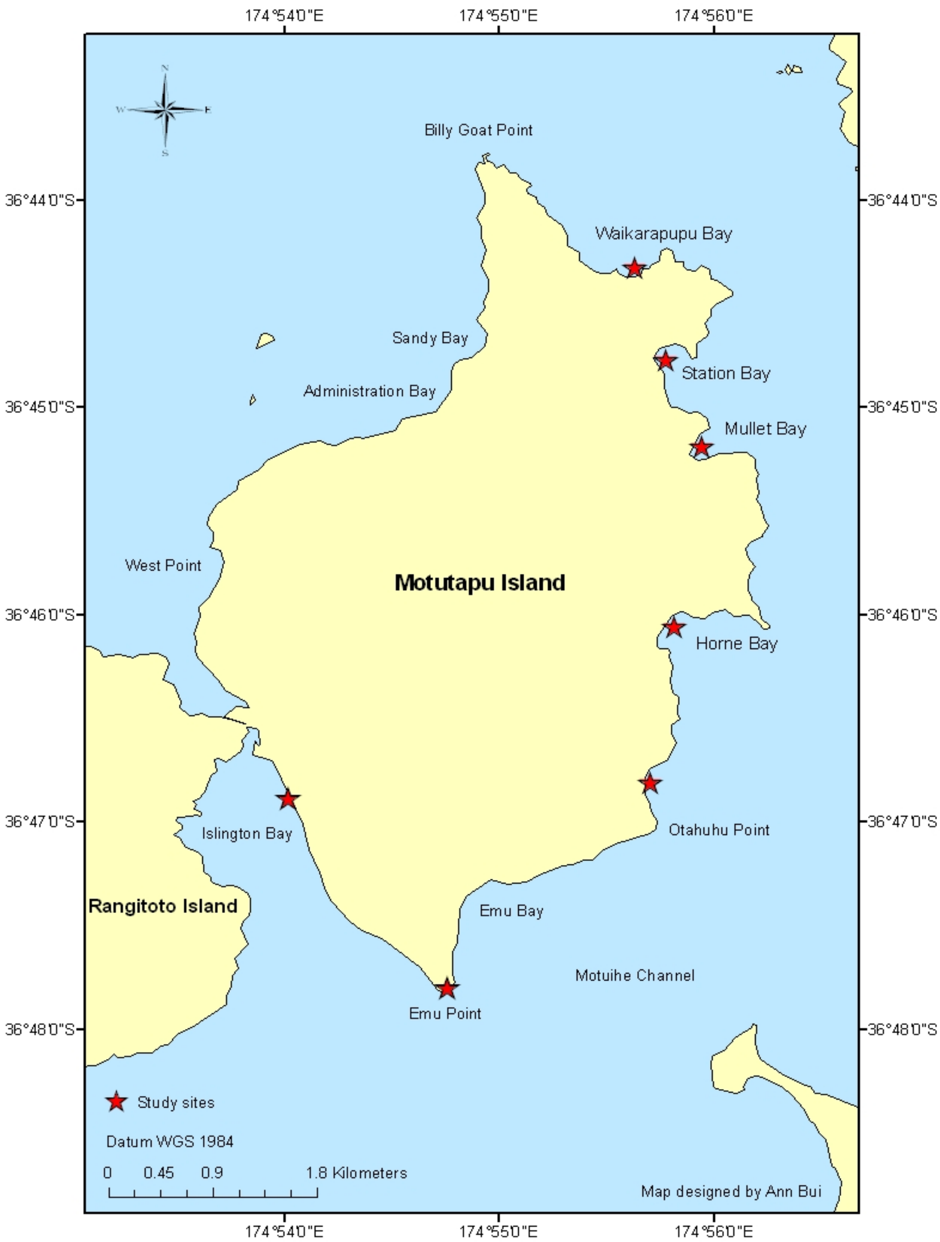

Figure 19 Location of survey sites on Motutapu Island.

Laboratory analysis of sand samples

Equipment and Reagents

All equipment and materials were available at Applied Science Laboratories, Wellesley Campus, Division of Applied Science, AUT.

Equipment

- VELP DK20 Heating digester
- VELP UDK 126A Distillation Unit
- 10 mL burette
- Digestion tube (42 x 300 mm Ø) for distillation unit
- Multi-sample shaker
- Whatman N^o 2 (70 mm Ø) filter paper
- Boiling bath
- Ultrospec 2100 pro U/V visible spectrophotometer

Reagents

- Catalyst mixture: potassium sulfate, copper(II) sulfate pentahydrate ($CuSO_4.5H_2O$) and selenium dioxide, at ratio 100:10 :2
- Concentrated sulfuric acid reagent grade 95–98%
- 35% hydrogen peroxide 4% boric acid
- 35% sodium hydroxide
- 0.047 $molL^{-1}$ hydrochloric acid
- Kjeldahl indicator as Tashiro's indicator (0.6 g methyl red : 50 mL 95% ethyl alcohol: 0.1 g methylene blue solution)
- 0.5 $molL^{-1}$ sodium hydrogen carbonate
- Acidic molybdate solution: 25 g of sodium molybdate in 5 $molL^{-1}$ sulfuric acid and made up to 1 L solution by 5 $molL^{-1}$ sulfuric acid
- Hydrazinium sulfate solution: dissolve 1.5 g of hydrazinium sulfate in de-ionised water and dilute to 1 L solution
- Potassium dihydrogen phosphate: standard solutions with series of concentration 0.1, 0.5, 1 and 3 ppm (or mgL^{-1}) of potassium dihydrogen phosphate

Procedure

Sample preparation

All sand samples were air-dried and passed through a 600 μm sieve prior to analysis.

Total nitrogen

The Kjeldahl method is widely used for estimating the nitrogen content of foodstuffs, fertilizers, and other substances. The sample is decomposed at 189°C in a boiling mixture of concentrated sulphuric acid and potassium sulphate with a selenium dioxide catalyst. Almost all organic and inorganic nitrogen is converted to ammonium sulphate; the only significant exceptions are nitrate and nitrite. The mixture is neutralised with sodium hydroxide and the ammonia formed is steam distilled from the mixture, trapped in boric acid and titrated against a standard hydrochloric acid solution. The calculated result is expressed as total Kjeldahl nitrogen (TKN).

The Kjeldahl method is applicable for samples containing either low or high concentrations of organic nitrogen but it requires a relatively large sample volume for low concentrations. It fails to account for some types of inorganic nitrogen in the form of azide, azine, azo, hydrazone, nitrate, nitrite, nitrile, nitro, nitroso, oxime and semi-carbazone.

Ten grams of each sand sample was transferred to a digestion tube with 5.5 g catalyst mixture, 7 mL concentrated sulfuric acid, 5 mL of hydrogen peroxide and several boiling granules. Then the mixture was digested for 30 minutes at 400°C in a Digester Unit. After digestion, the tube was left to cool to 50−60°, approximately 15 minutes, then 50 mL of ammonia-free distilled water and 50mL of 35% sodium hydroxide was added into each tube and the mixture was steam distilled until 150 mL of distillate was collected into 25 mL of 4% boric acid solution. This distillate solution then was titrated with 0.047M HCl and Kjeldahl indicator, giving an end point colour change from green to light pink. The volume of HCl used was recorded and the concentration of total nitrogen ($N\text{-}NH_4$) in each sand sample was determined in accordance with the following formulae. This method is modified from that in the VELP UDK 126A manual for total nitrogen determination in soil.

It has been assumed that 0.6587 mg of $N\text{-}NH_4$ requires 1 mL of acid 0.047 $molL^{-1}$ (VELP manual) to reach the endpoint of reaction.

The concentration ($mgKg^{-1}$ or ppm) of nitrogen in a sample is

$$\frac{\text{Volume of HCl (mL) x 0.6586 mg}}{\text{0.01 Kg of sample}} = \text{mg/Kg or ppm}$$

Labile phosphate

The principle of this method is to produce molybdophosphoric acid, which upon selective reduction, has a blue colour. The intensity of the blue colour is proportional to the amount of phosphate initially incorporated in acid.

There are numerous soil tests used for measuring the availability of soil phosphorus. In nature, phosphorus occurs in the form of phosphate ions, especially the orthophosphate form. Phosphates were extracted from sand samples according to Olsen's method (as cited in Sims 2000), using 0.5 $molL^{-1}$ Sodium bicarbonate. This method is recommended for calcareous sediments with pH > 7 (Frank *et al*. 1998). The Olsen method is based on the process of desorption/ ion exchange, deemed the most suitable method for determining inorganic phosphate bioavailability under geochemical conditions (Branom & Sarkar 2004), especially for labile orthophosphate in soil (Thomas & Peaslee 1973).

However, Olsen's method had some limitations: it just measures the free (available) inorganic phosphorus in soil rather than the organic phosphorus that is produced by a decomposing carcass; the inorganic phosphorus is converted into organic phosphorus by bacteria. The Olsen P test also can produce variable results; actual phosphorus concentrations could ± 20% of the read result from Olsen P (McKie 2005). This technique has been used in many laboratories to determine phosphorus concentrations in calcareous soils of pH greater than 7.4 (Menon *et al*. 1991); as sandy beaches usually are covered by seawater at high tide, the pH of sand would be affected by the pH of seawater, and as seawater is slightly alkaline, with a pH approximately 7.4–8.5 (Byrne 2002), Olsen's method was the preferred method as was used in this thesis.

The concentration of phosphate was determined using the molybdenum blue method (Vogel 1961); 4 g dried sand from each sample was added to 20 mL 0.5 $molL^{-1}$ sodium bicarbonate solution and shaken at 100 excursions per minute (epm) for 30 minutes at room temperature (24–27°C). The extracted solution was then filtered through N^o2 filter paper. After filtration, a 5 mL sample solution was mixed with 1 mL acidic molybdate solution and 0.4mL hydrazinium sulfate solution, diluted to 10mL with distilled water and immersed in a boiling bath for 10 minutes (Vogel 1961), producing a blue-coloured solution. Absorbance of this blue solution then was measured by UV/visible spectrophotometer at 830 nm. A calibration curve of the relationship between phosphate concentration and absorbance of standard solutions was constructed and used to determine the concentration of phosphate in the sample solution. The result of phosphate concentration in extracting solution was converted to mg/kg or ppm of initial sand sample, in accordance with the following formula:

Concentration of PO_4^{3-} initially (mg/Kg or ppm) = concentration of PO_4^{3-} in Olsen extract (mg/L) x 5.

Faunal surveys

The final component of objectives 1 and 2 of this research programme required an evaluation of the effect of cetacean burial on intertidal infauna at Muriwai Beach, and an appraisal of the appropriateness of intertidal shores on Motutapu Island for cetacean burial.

Muriwai Beach

Four transects were run perpendicular to the shore, with 5 replicate samples collected from each of five sites extending from extreme high water (0m), to 1, 2, 3, and 4 m vertical height (determined by theodolite) from high water down the shore (Figure 20). The core sampler used to collect replicate samples has a surface-sampling area of 0.013 m^2, and was sampled at each site to a depth of 20 cm. Samples were processed in the field through a 1 mm sieve, then immediately fixed in 40% isopropyl alcohol in individually labeled bottles. Identification was undertaken in the laboratory using standard light-microscopic equipment. Species abundances reported herein are presented in terms of sampled volume, $0.026m^3$.

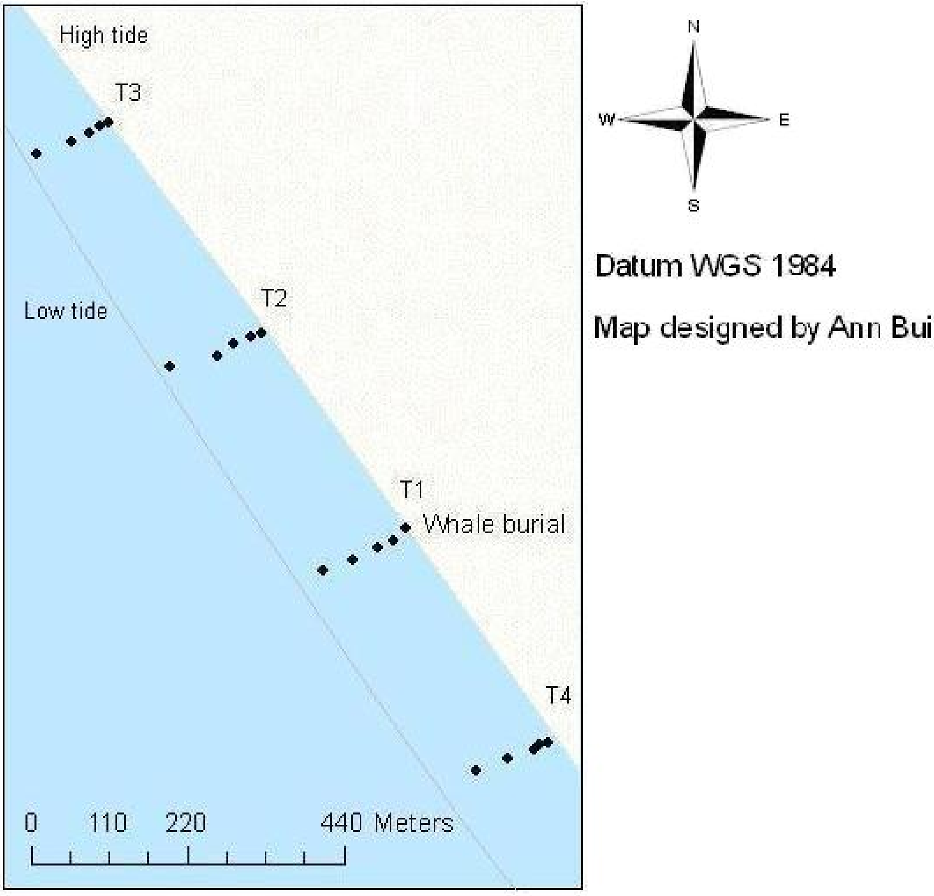

Figure 20: Faunal survey at Muriwai Beach

Motutapu Island intertidal species inventories

In addition to sand samples being collected at the six beaches detailed in Table 2, a complete faunal inventory was obtained for these six shores, within soft and upon hard substrata. Survey methodology was essentially the same as that of Palacio (2008), with intertidal surveys being undertaken immediately prior to, at, or following extreme low water, on tides usually of 0.3 m or less. Multiple sites examined on any given date were within 15 minutes transit time by boat; one site was surveyed prior to and one immediately following low water. In the former case, surveys commenced in the upper shore and worked towards low water with the receding tide; in the latter case, surveys commenced at low water and progressed up the shore with the advancing tide.

A transect was run from high to low tidal levels through the intertidal platform at a place deemed representative of the overall shore; 20 m either side of this transect all macro-flora or -fauna were identified to the lowest practical taxonomic level during 15–120 minute surveys, depending on the nature of the intertidal platform (whether soft or hard). A survey was considered complete following an exhaustive examination of all obvious habitat types within the belt transect when no additional species were encountered after 10 minutes of searching. The time taken for each survey usually depended on the habitat complexity of any shore, as muddy habitats with limited hard structure took considerably less time to document macro-faunal and -floral composition than, for example, the more structured reefs.

The majority of taxa were identified in the field, although some infaunal taxa were sieved, sorted, preserved in 5% buffered formalin, and identified in the laboratory.

Upon identification species data were then compared with those inventories from 290 other intertidal shores extending from Whangarei in the north to Tauranga Harbour in the south, for which full taxonomic inventories are available (AUT Biodiversity database) (Palacio 2008). Palacio (*loc. cit.*) had attributed an index of rarity to each species occurring within or upon discrete habitat types throughout this region, based on a tally of the number of occurrences of each species in the total number of surveyed sites within a particular habitat type. For instance, should one species occurring at a site on Motutapu Island be recorded at 2 of 123 surveyed sites within a rocky-shore habitat (Palacio 2008), then it would be classed as a *very rare* species throughout the surveyed region (2 being approximately 2% of 123) in accordance with Palacio's schema (see Table 3).

Table 3: Ordination of rarity index using a 7-point scale of species occurrences in 296 intertidal sampling sites (from Palacio 2008)

Occurrence (%)	Rarity Index
< 5	very rare
5–10	rare
11–25	uncommon
26–50	frequent
51–75	common
76–95	very common
96–100	ubiquitous

A second index proposed by Palacio (2008) was that of relative species richness. The maximum and minimum number of species (species richness) encountered on shores within a certain habitat type was shown to vary throughout the region surveyed by Palacio (*loc. cit.*). A 7-point ordination of species richness was proposed to rank the richness of a given site relative to other sites in comparable habitat, particularly the minimum and maximum counts of species recorded for a particular habitat type (Palacio 2008). The ranking of a site as one of *very low* to *very high* richness is a function of the total species count for a given site divided by the maximum number of species identified from a given habitat type in all surveys. For instance, should the maximum number of species identified by Palacio (2008) from any surveyed rocky reef site be 180, and the total species count on a rocky shore at Motutapu Island was 60, then the Motutapu site would have a *medium* species richness for rocky shores for the northeastern New Zealand region (see Tables 4, 5).

Table 4: Ordination of Species Richness index using a 7-point scale for all intertidal habitat types (from Palacio 2008)

Species richness (%)	**Richness index**
<5	very low species richness
5–10	low species richness
11–25	fairly low species richness
26–50	medium species richness
51–75	fairly high species richness
76–95	high species richness
96–100	very high species richness

Table 5: Ordination of species richness using a 7-point scale by habitat type (number in parentheses is maximum species count for a given habitat type, of those habitats surveyed on Motutapu Island). Numbers in columns are absolute species counts, or ranges in species count. (From Palacio 2008)

Species Richness index	**Marine Hard (180)**	**Soft Marine (85)**	**Brackish Soft (23)**
Very low	< 9	< 5	< 2
Low	9−18	5−8	2
Fairly low	19−45	9−21	3−5
Medium	46−90	22−42	6−11
Fairly high	91−134	43−63	12−17
High	135−170	64−80	18−21
Very high	171−179	81−85	22 or 23

Geographical Information Systems (GIS)

In order to determine the spatial changes in nutrient concentration, GPS coordinates were recorded for each sample at each location and a spatial database was developed in a GIS using ArcMap 9.3 software (Minami 2008). As the GPS accuracy ranged from 5–10 m, it was not possible to return to the exact sampling site at each sampling event.

At each sampling site, nitrogen and phosphate concentrations were recorded and later included in the GIS. In the GIS, concentrations of each were classified into five categories using Jenk's natural breaks (Minami 2008) for the Muriwai Beach location. Concentrations of nitrogen and phosphate at the Pakiri location were classified according to these same categories from the Muriwai Beach location. Maps then were used to illustrate changes in concentration with higher concentration points appearing darker in colour and lower concentration points appearing lighter.

Statistical analyses

<u>Concentrations of nitrogen and phosphate</u>

All the results of chemical analysis were analysed by Minitab (version 15) (Appendix 1.1–2.6). ANOVA or General Linear Model (GLM) was used when data was of normal distribution with equal variance. Null hypothesis of these tests is that no difference in the mean values of nitrogen and phosphates exists.

If the data showed non-normal distribution or had unequal variances, Kruskal-Wallis test (nonparametric) was used to test for any difference between medians for two or more groups of sample. In this case, samples were grouped by the distance from the centre of whale burial to sampling site. In this test, the null hypothesis was the medians of these groups of sample were all equal; an alternative hypothesis was the medians were not all equal. If the p-value was less than 0.05 a null hypothesis was rejected.

<u>Species inventories at Muriwai Beach</u>

All species lists for each sampling site were added into Primer 6 software for Multidimensional scaling (MDS) to express degrees of similarity or dissimilarity in species assemblages between sampling sites. Points representing similar diversity tend to cluster together in a specific region of space. One way ANOVA was used to determine whether significant differences in species assemblages occurred between samples taken at different tidal heights (1 m vertical increments from high water) along transects down-shore of whale burial site (Appendices 3.1–3).

Results

Motutapu Island

More than 30 soft- or mobile (shell gravel and cobble) shores occur around Motutapu Island, but most are small and surrounded by shallow rocky reefs; these shores are inaccessible to a large vessel towing a whale carcass, and beach size renders them inappropriate for burial of such carcasses. Six of these soft shores could be relatively easily accessed by a large vessel.

In addition to vessel access, an appropriate location for cetacean burial must have road or field access to enable large digging equipment to reach the burial site; the site otherwise would have no significant archaeological value, or nearby residents or dwellings. None of Islington, Mullet, or Waikarapupu Bays and the shore near Otahuhu Point had road access, so all would be inappropriate sites for cetacean burial. Station Bay had appropriate vessel access, road and pasture access, no dwellings and no known significant archaeological site, and meets those criteria required to bury whales within it. Home Bay had appropriate boat and vessel access, but adjacent dwellings and significant archaeological sites render it inappropriate for cetacean burial.

<u>Faunal diversity</u>

Of all surveyed shores Home Bay had the highest recognised hard-shore species richness (180 taxa (soft and hard)); in accordance with the species richness index of Palacio (2008) (Table 5) this shore has a *very high* species richness. To the contrary the soft shore at Home Bay, with 17 taxa, had *low* species richness. Other surveyed shores, in descending order of species richness, were Waikarapupu Bay, with 153 taxa (soft and hard); Emu Point, 130 taxa; Station Bay, 110 taxa; Islington Bay, 92 taxa; Mullet Bay, 8 taxa; and Otahuhu Point, 4 taxa. When evaluating soft-shore species (soft and hard) richness alone, Station Bay had the highest species richness of all surveyed soft shores on Motutapu Island, and *fairly high* species richness in accordance with Palacio (2008).

Table 6: Number of species found at surveyed shores, Motutapu Island

Location	**Shore type**	**Species Richness**
Islington Bay	Hard (rock)	51
Islington Bay	Soft (mud and sand)	41
Emu Point	Hard (rock)	130
Near Otahuhu Point	Soft (gravel and sand)	4
Home Bay	Hard (rock)	180
Home Bay	Soft (gravel and sand)	17
Mullet Bay	Soft (gravel and sand)	8
Station Bay	Soft (rock, gravel, sand and mud)	110
Waikarapupu Bay	Hard (rock)	142
Waikarapupu Bay	Soft (gravel and sand)	11

<u>Sediments</u>

Average nitrogen and phosphate concentrations (± standard deviation) were calculated for the three replicate samples taken from each shore on Motutapu Island. Of these shores Station Bay had the highest average concentration of both nitrogen (140.1 ± 4.307 ppm) and phosphate (10.1 ± 0.364 ppm) (Figure 21), with nitrogen progressively decreasing from Islington Bay (111 ± 2.597 ppm), Home Bay (105.1 ± 4.046 ppm), Waikarapupu Bay (95.9 ± 8.511 ppm) and Mullet Bay (89.1 ± 3.430 ppm); a small shore near Otahuhu Point had the lowest concentration of nitrogen (81.638 ± 7.950 ppm) (Figure 21).

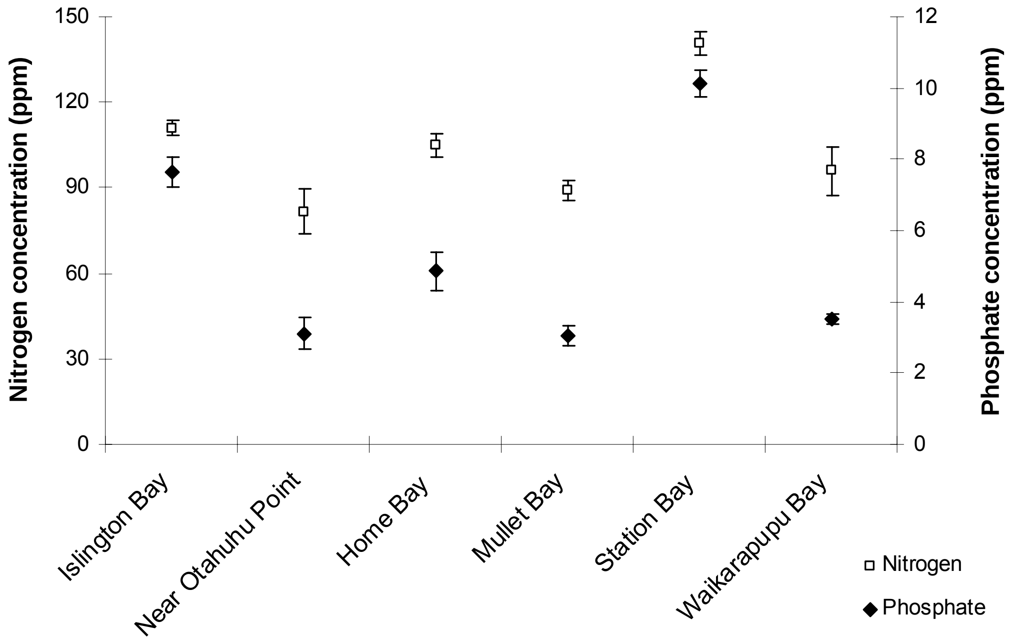

Figure 21: Mean (SD +/-) concentrations of of nitrogen and phosphate in different beaches on Motutapu Island

The concentration of phosphate showed a similar trend to that of nitrogen (Figure 21). Station Bay had the highest concentration of phosphate, nearly twice as high as that at Home Bay (4.87 ± 0.535 ppm), and three times that at Mullet Bay (3.034 ± 0.275 ppm), Waikarapupu Bay (3.526 ± 0.137 ppm) and the shore near Otahuhu Point (3.115 ± 0.429 ppm). The concentration of phosphate recorded at Islington Bay (7.632 ± 0.43 ppm) was the second highest phosphate concentration recorded at the six surveyed sites.

Pakiri Beach

<u>Surface sediments</u>

A total of 154 samples were collected from this beach over the course of five surveys. The concentrations of nitrogen and phosphate prior to whale burial did not change remarkably along any transect (Figure 22, 24 respectively), ranging approximately 20–30 ppm for nitrogen and 0.4–1ppm for phosphate. ANOVA identified no difference in average nitrogen and phosphate concentrations between sites (p-value (= 0.195 and 0.246) greater than 0.05). These concentrations could be considered background values for these sediments on this beach.

For analysis, sampling sites from the centre of the whale burial site were grouped into one of three categories: 1, 0–15 m; 2, 15 m < *x*–40 m; and 3, > 40 m from the centre of the burial site. The concentration of nitrogen and phosphates in surface sands changed significantly from week 0 background levels to those observed 2.5 weeks post burial, especially immediately above the whale burial site. Two and a half weeks post cetacean burial nitrogen concentrations in surface sediments above the burial site, at 90 ppm, were almost three times those prior to burial; phosphate concentrations were almost four times greater; with increasing distance from the burial site concentrations of nitrogen and phosphates decreased, although no significant difference was found in the concentrations of nitrogen and phosphates in week 2.5 between sites 0–15 m, $15 < x \leq 40$ m, > 40 m from the burial site (Kruskal-Wallis and ANOVA tests (p-value (0.052 and 0.163) >0.05).

Concentrations peaked during the second sampling event (2.5 weeks post burial), and slightly decreased 6 weeks post burial, albeit at concentrations considerably greater than those encountered prior to burial; concentrations were noticeably highest above the site of whale burial, and dropped at 12 m distance from the centre of burial (Figure 22, 24); at distances greater than 12 m from this central burial site concentrations fluctuated between 20 and 40 ppm for nitrogen and 0.5 and 1.5 ppm for phosphate.

With the exception of phosphate concentrations in week 24.5, mean nitrogen and phosphate concentrations 6–24.5 weeks post burial usually were significantly different between sites 0–15 m, $15 < x \leq 40$ m, > 40 m from the central whale burial site, although in most cases as data were non-normal in distribution, Kruskal-Wallis could not identify precisely where any significant change occurred. According to Tukey test in General Linear Model for phosphate at week 17, p-values proved mean phosphate concentrations in samples collected up to 15 m from the central burial site were significantly different from mean concentrations in samples collected between 15 and 40 m (p-value 0.002 <0.05) and greater than 40 m from the burial site (p-value 0.0001 <0.05); with confidence intervals of both means being less than 0, mean concentrations of nitrogen and phosphates to distances of 15 m from the burial site were greater than those between 15 and 40 m, and > 40 m from the burial site.

Table 7: Statistical tests to compare means in concentrations of nitrogen (N) and phosphate (P) for samples at increasing distances from whale burial, Parkiri Beach (additional abbreviations: A, ANOVA test; KW, Kruskal-Wallis test; GLM, General linear model; NSD, No significant difference; D, Difference)

	Chemical	**Normality**		**Equal variance**	**Test used**	**p-value**	**Result**
		Data	Residuals				
Week 0	N	Yes	-	Yes	A	0.195	NSD
	P	No	No	Yes	KW	0.246	NSD
Week 2.5	N	No	-	No	KW	0.052	NSD
	P	Yes	-	Yes	A	0.163	NSD
Week 6	N	No	No	Yes	KW	0.009	SD
	P	No	No	Yes	KW	0.013	SD
Week 12	N	No	-	No	KW	0.016	SD
	P	No	No	Yes	KW	0.044	SD
Week 17	N	No	No	Yes	KW	0.000	SD
	P	Yes	-	Yes	GLM	0.000	SD
Week 24.5	N	No	No	Yes	KW	0.017	SD
	P	No	No	Yes	KW	0.062	NSD

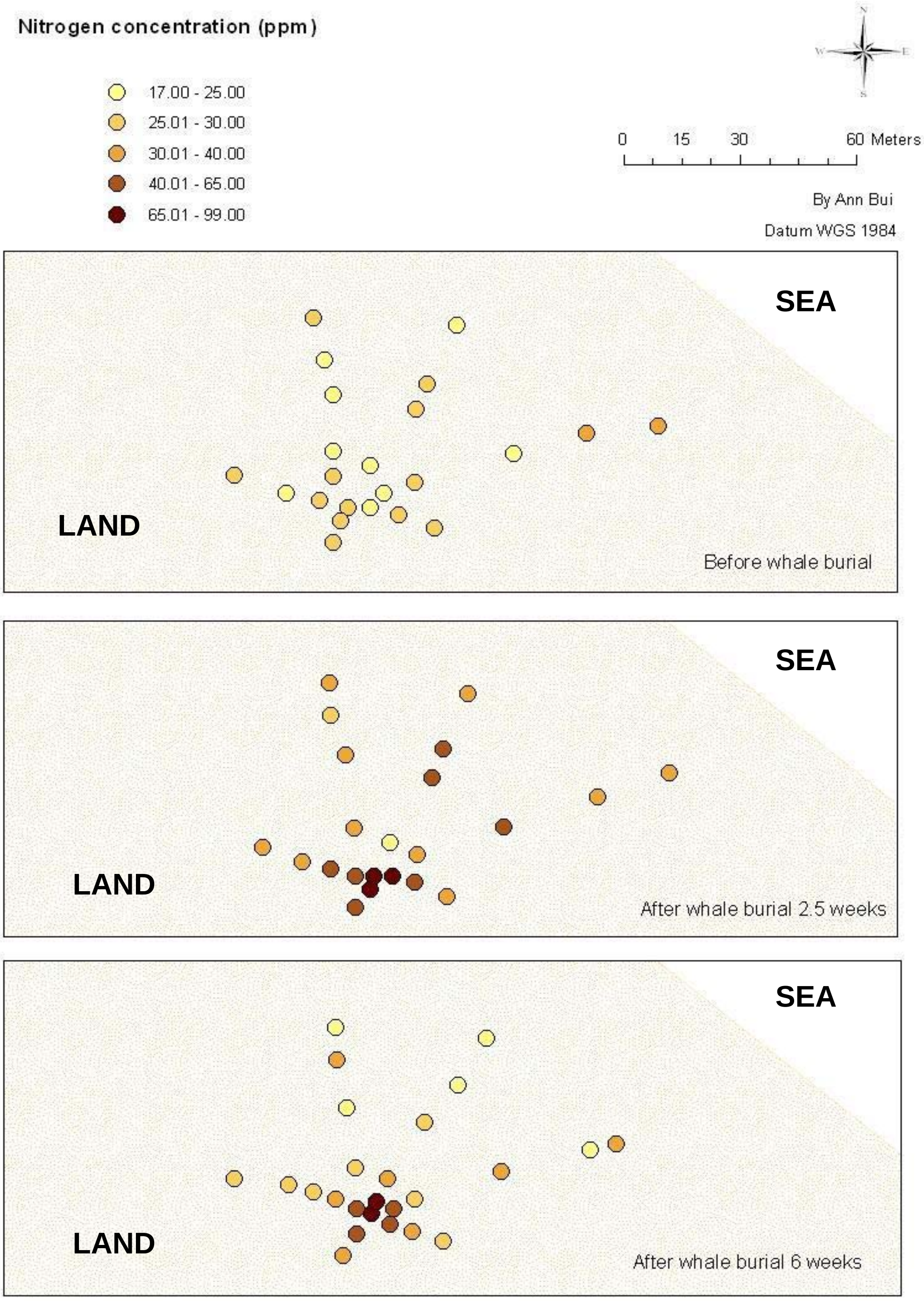

Figure 22: Nitrogen concentration (ppm) prior to, 2.5 and 6 weeks post burial, Pakiri Beach

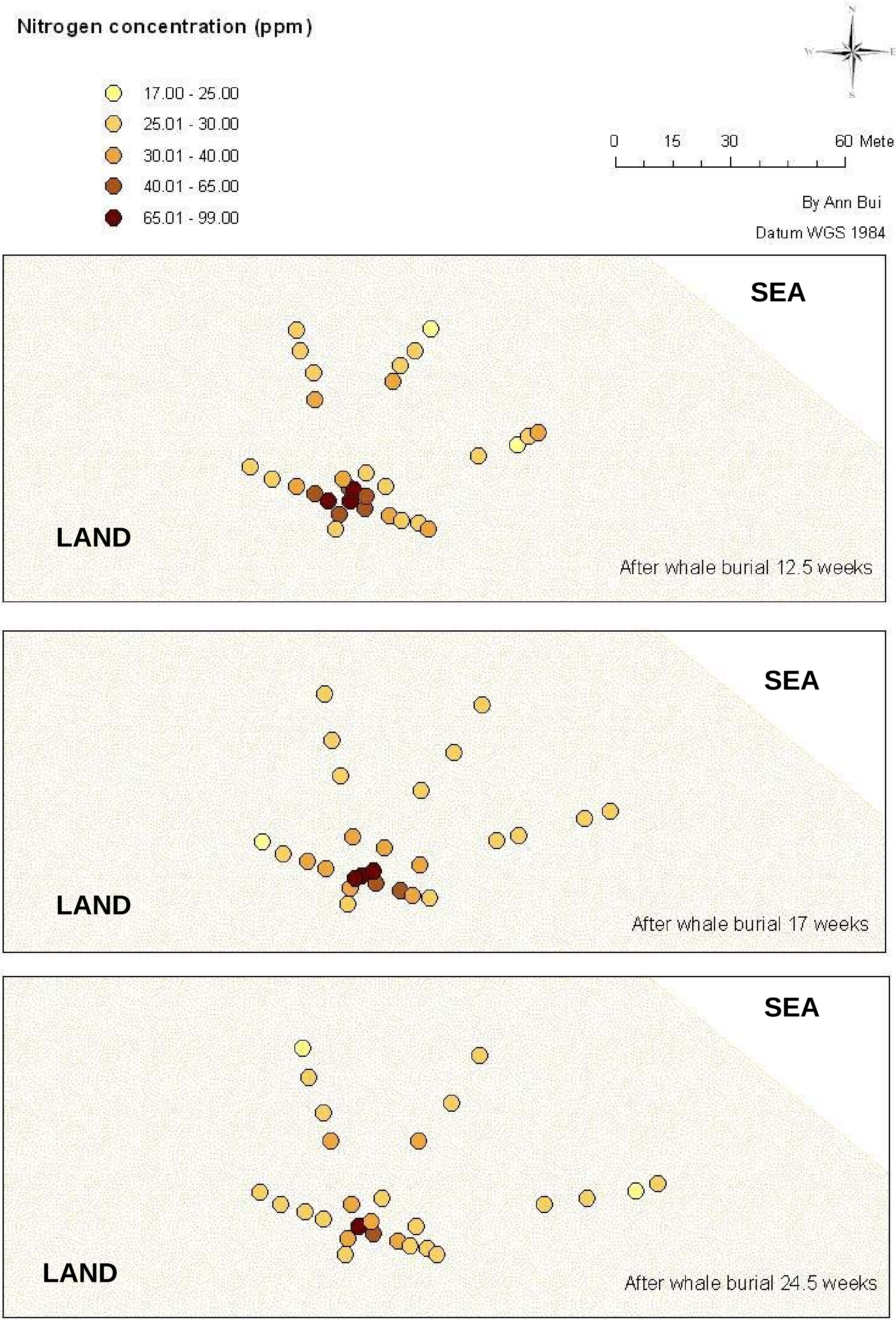

Figure 23: Nitrogen concentration (ppm) 12.5–24.5 weeks post burial, Pakiri Beach

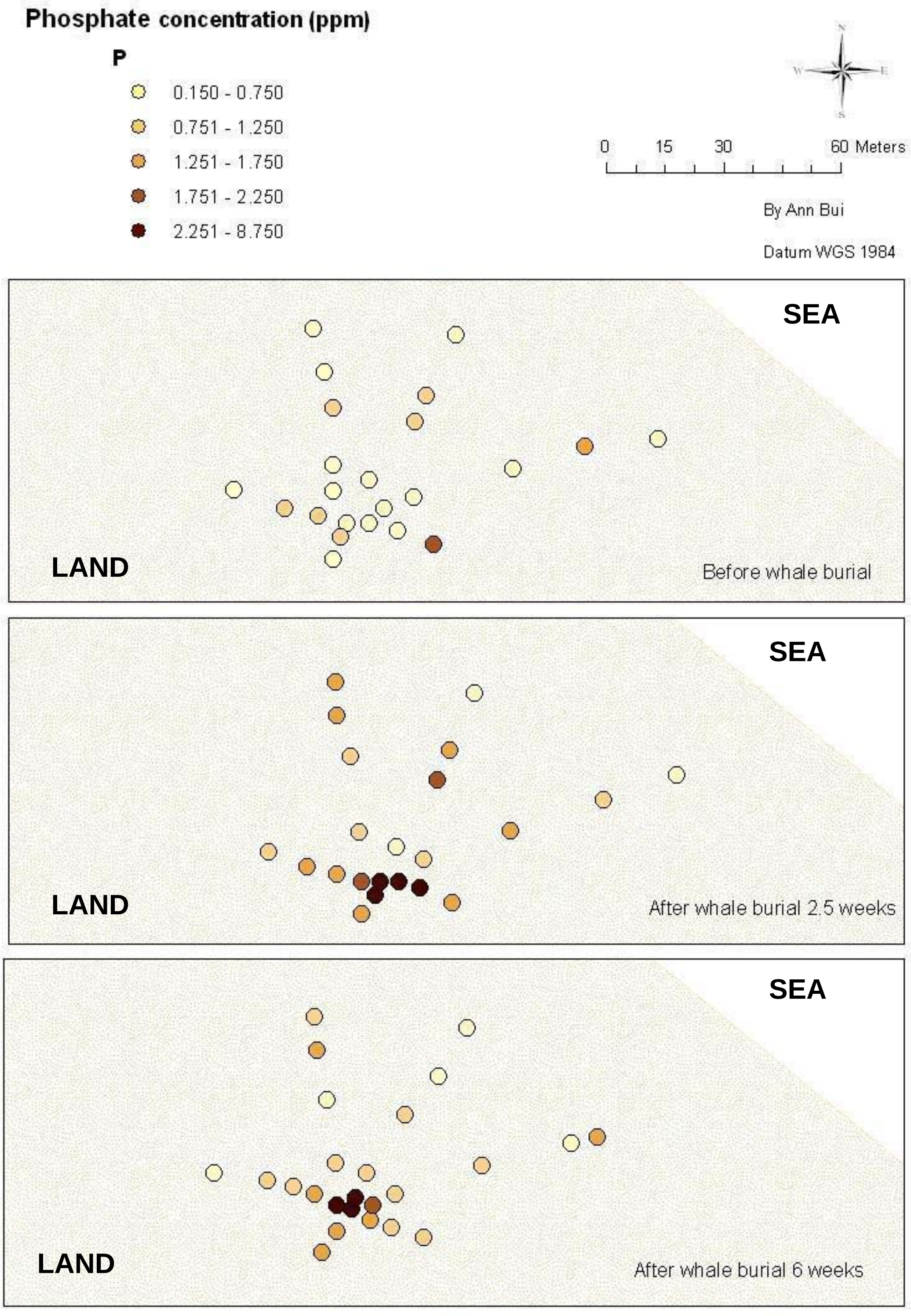

Figure 24: Phosphate concentration (ppm) prior to, 2.5 and 6 weeks post whale burial, Pakiri Beach

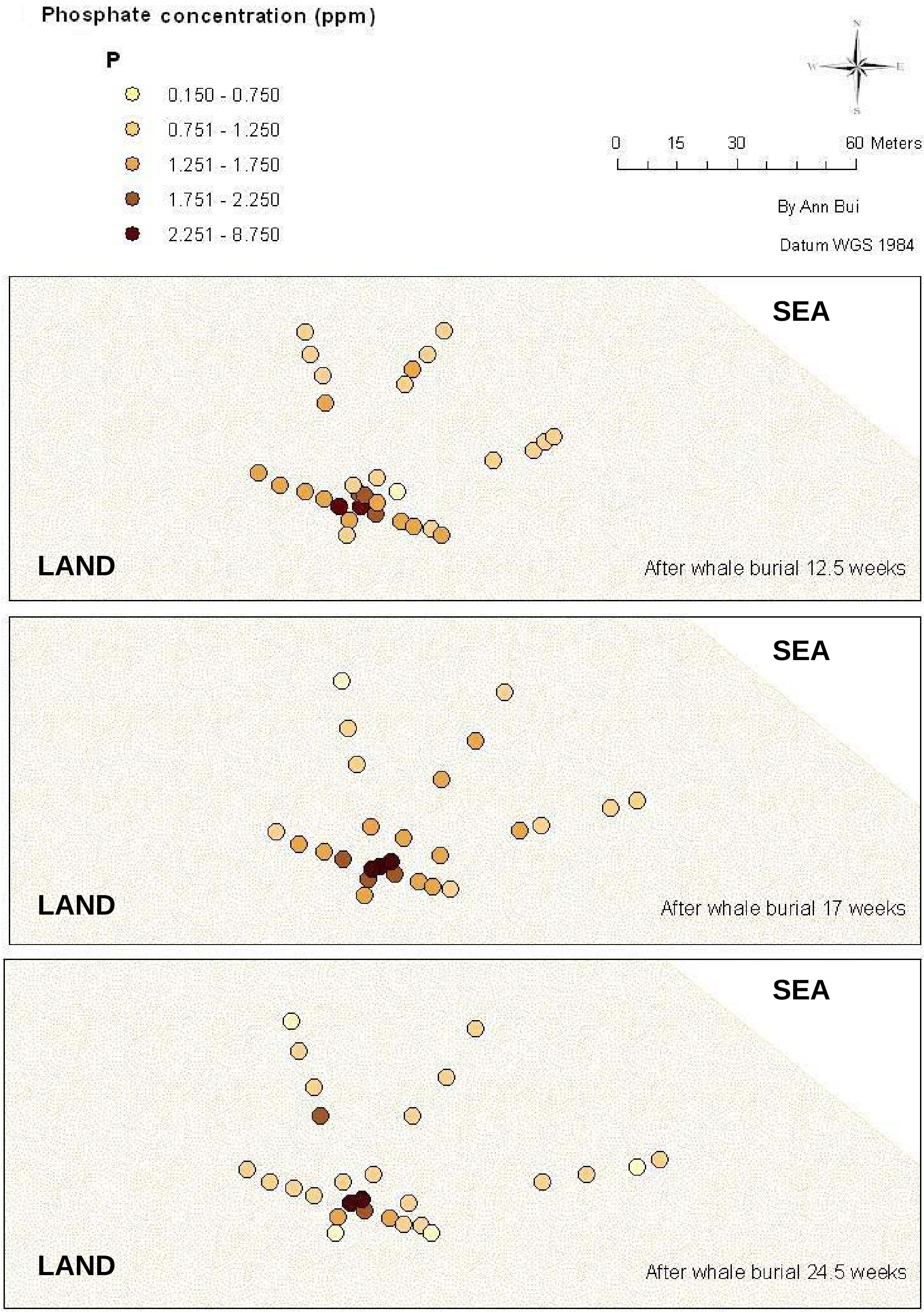

Figure 25: Phosphate concentration (ppm) 12.5–24.5 weeks post burial, Pakiri Beach

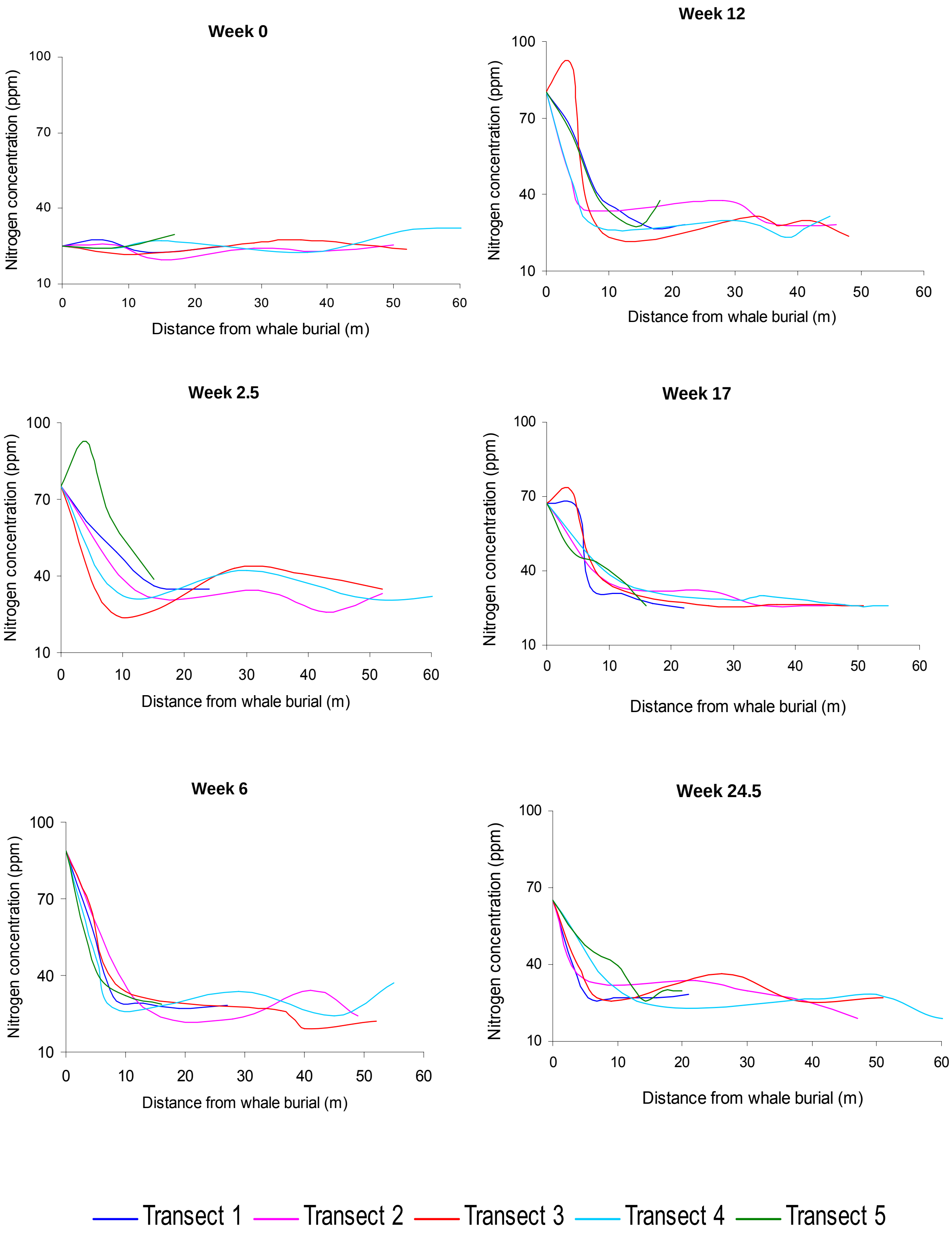

Figure 26: Relationship between surface-sand nitrogen concentration and distance from whale burial over 6 months, Pakiri Beach

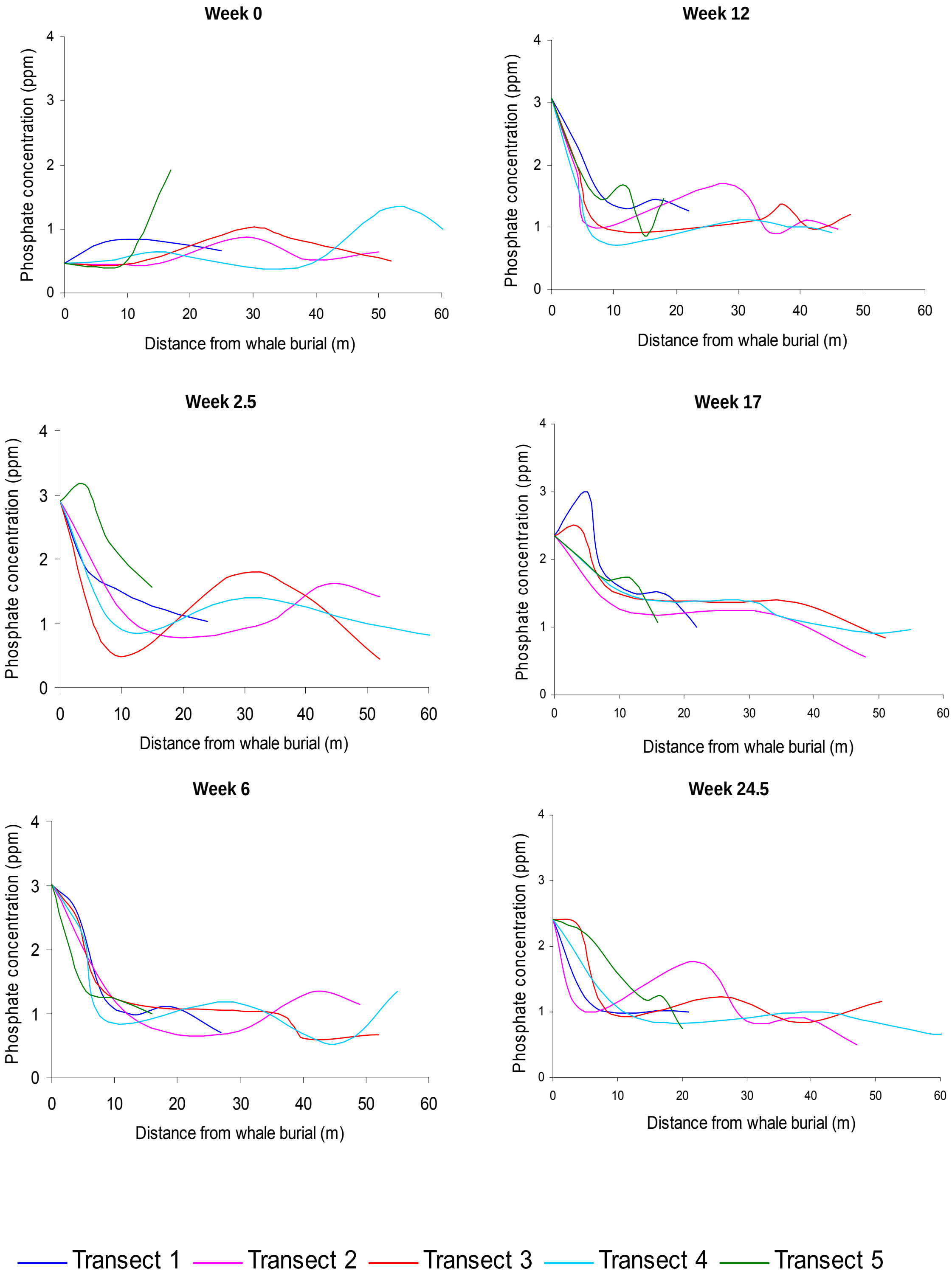

Figure 27: Relationship between surface-sand phosphate concentration and distance from whale burial over 6 months, Pakiri Beach

Deep-core sampling

At Pakiri Beach the pungent odor of rotting whale was most apparent in cores taken above the whale burial site, with surface concentrations of nitrogen and phosphate high, then decreasing slightly to 1 m depth, before increasing again; at 2 m, just above water table, nitrogen and phosphate concentrations were very high (80 ppm and 6ppm respectively). Concentrations of both nitrogen and phosphate 8 m from the burial site did not differ remarkably with depth, fluctuating between 20 and 30 ppm, and 0.6 and 1.5 ppm respectively (Figure 28).

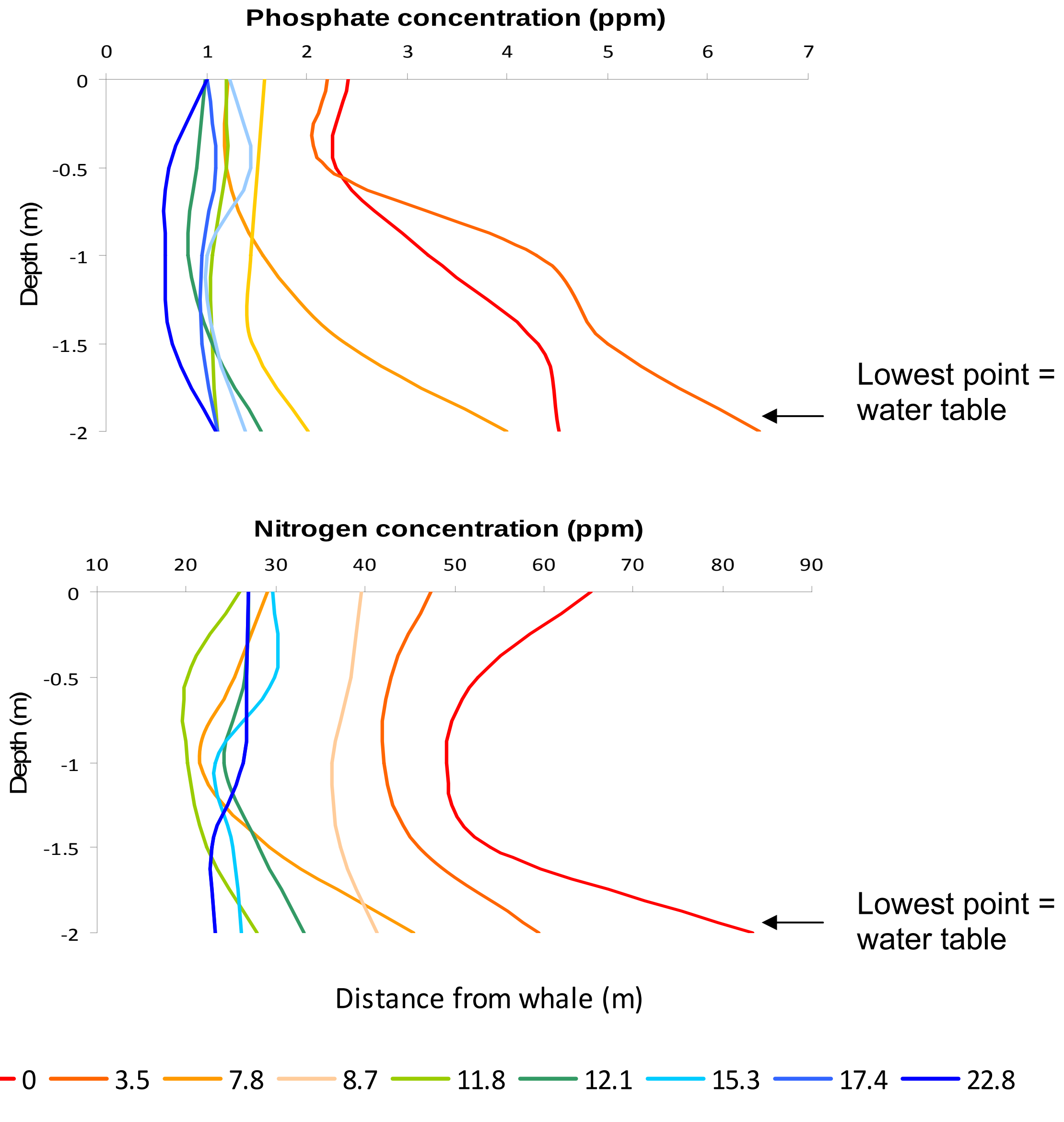

Figure 28: Relationship between concentration of nitrogen and phosphate with subsurface depth and distance from whale burial centre at Pakiri beach

Muriwai Beach

<u>Surface sediments</u>

As for Pakiri Beach, those sites along transects at Muriwai Beach were grouped for statistical analysis, although given the length of transects, into one of four categories instead: 1, 0–40 m; 2, $40 < x \leq 80$ m; 3, $80 < x \leq 120$ m; and 4, > 120 m.

More than 400 samples were collected from this beach over the course of five surveys. Background concentrations of nitrogen and phosphate (those prior to whale burial) were about 20–30 ppm and 0.3–2 ppm respectively. ANOVA identified no significant difference between mean nitrogen and phosphate concentrations in surface sediments between sites along transects prior to whale burial (p-value = 0.556).

Immediately above the whale burial site the concentration of nitrogen in surface sands changed significantly from week 0 background levels to those observed 1.5 weeks post burial (to 90 ppm), whereas the concentration of phosphates changed only slightly (to 3 ppm). Concentrations of these two continued to increase 4.5 weeks post burial, with nitrogen and phosphate reaching almost 100ppm and more than 8ppm respectively. Additionally, 4.5 weeks post burial, significantly elevated concentrations of both nitrogen and phosphate occurred in surface sands to least 40 m from the site of burial, extending directly down the shore but not dispersing along transects to the northwest and southwest. Elevated concentrations of both nitrogen and phosphate also were encountered toward low water 4.5 weeks post burial, but these are attributed to an extensive diatom bloom that extended the length of beach, rather than to any effect of cetacean burial. Both nitrogen and phosphate concentrations remain high (~ 100 ppm and 3 ppm respectively) 10.5 weeks post burial, but these had begun to decrease by week 21, during which time maximum nitrogen concentrations were 78 ppm and phosphate concentrations 59 ppm, still considerably higher than levels observed prior to whale burial.

In all weeks, except week 0, at least one mean value of nitrogen and phosphate concentration in samples collected between 0 and 40 m, 40 and 80 m, 80 and 120 m, and > 120 m was significantly different from others within these ranges (Appendices 2.1–2.6). Most concentration data were non-normal in distribution, requiring Kruskal-Wallis tests to be used, except that for phosphate concentrations during week 1.5. With a p-value of the comparison test less than 0.05, and confidence intervals of difference of means less than 0 (Appendix 2.2), Tukey test in General Linear Model for comparing the average concentration of phosphate between 0 and 40 m, with concentrations between 40 and 80 m, 80 and 120 m and > 120 m in week 1.5 revealed mean phosphate concentrations between 0 and 40 m to be significantly greater than those between 40 and 80 m, 80 and 120 m and > 120 m from the site of whale burial.

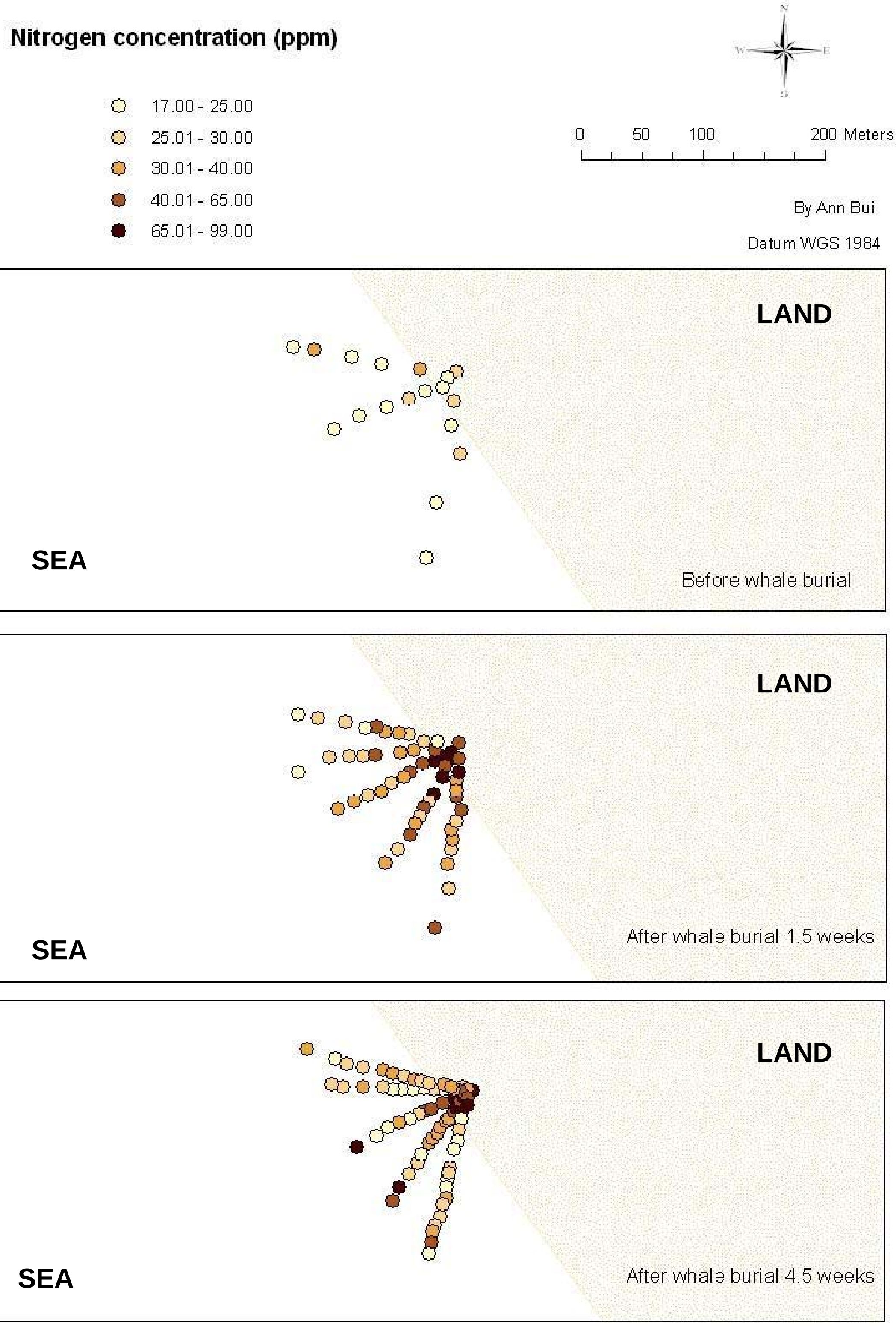

Figure 29: Surface-sand nitrogen concentration (ppm) from beginning (before whale burial), 1.5 and 4.5 weeks at Muriwai Beach

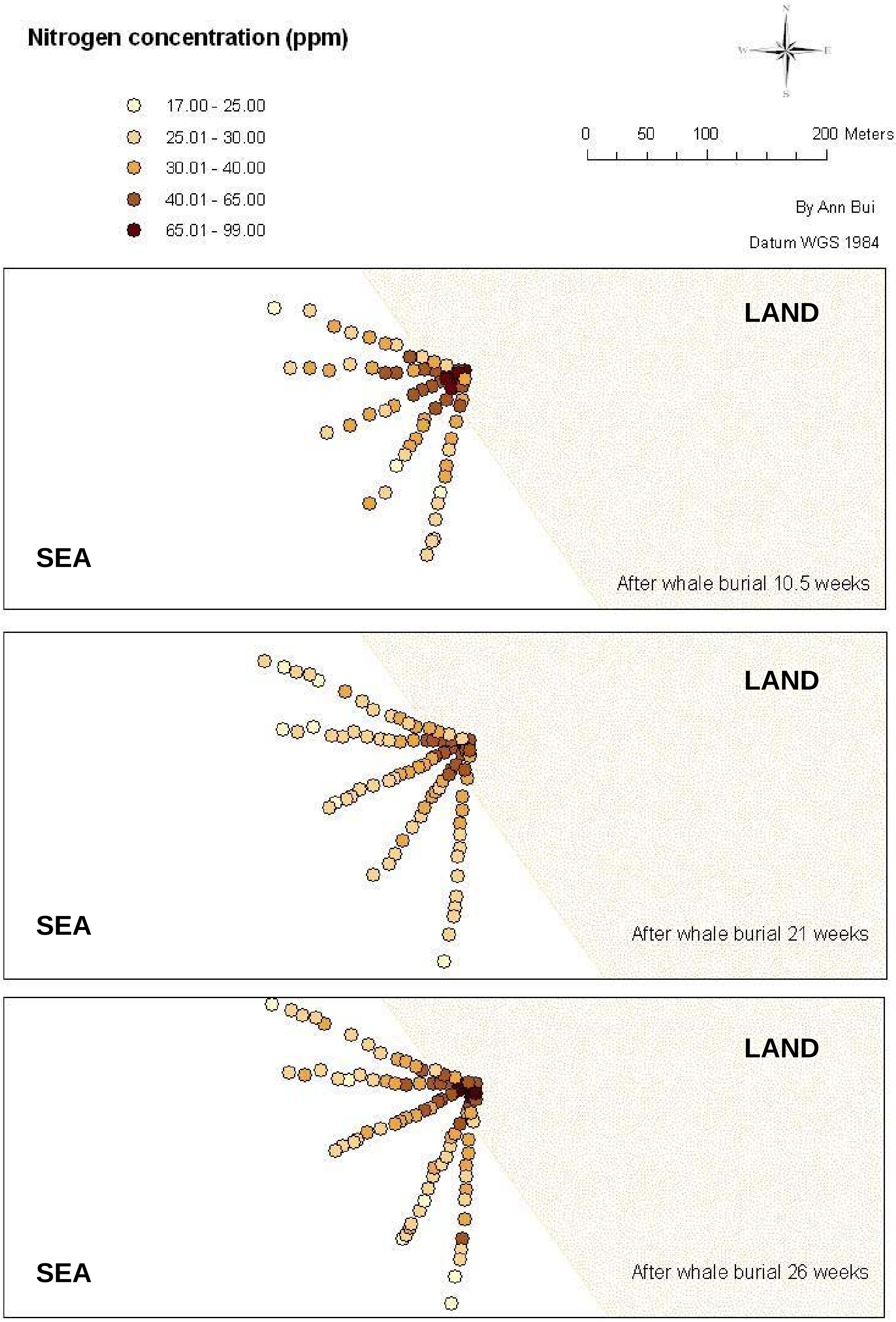

Figure 30: Surface-sand nitrogen concentration (ppm) 10.5–26 weeks post whale burial, Muriwai Beach

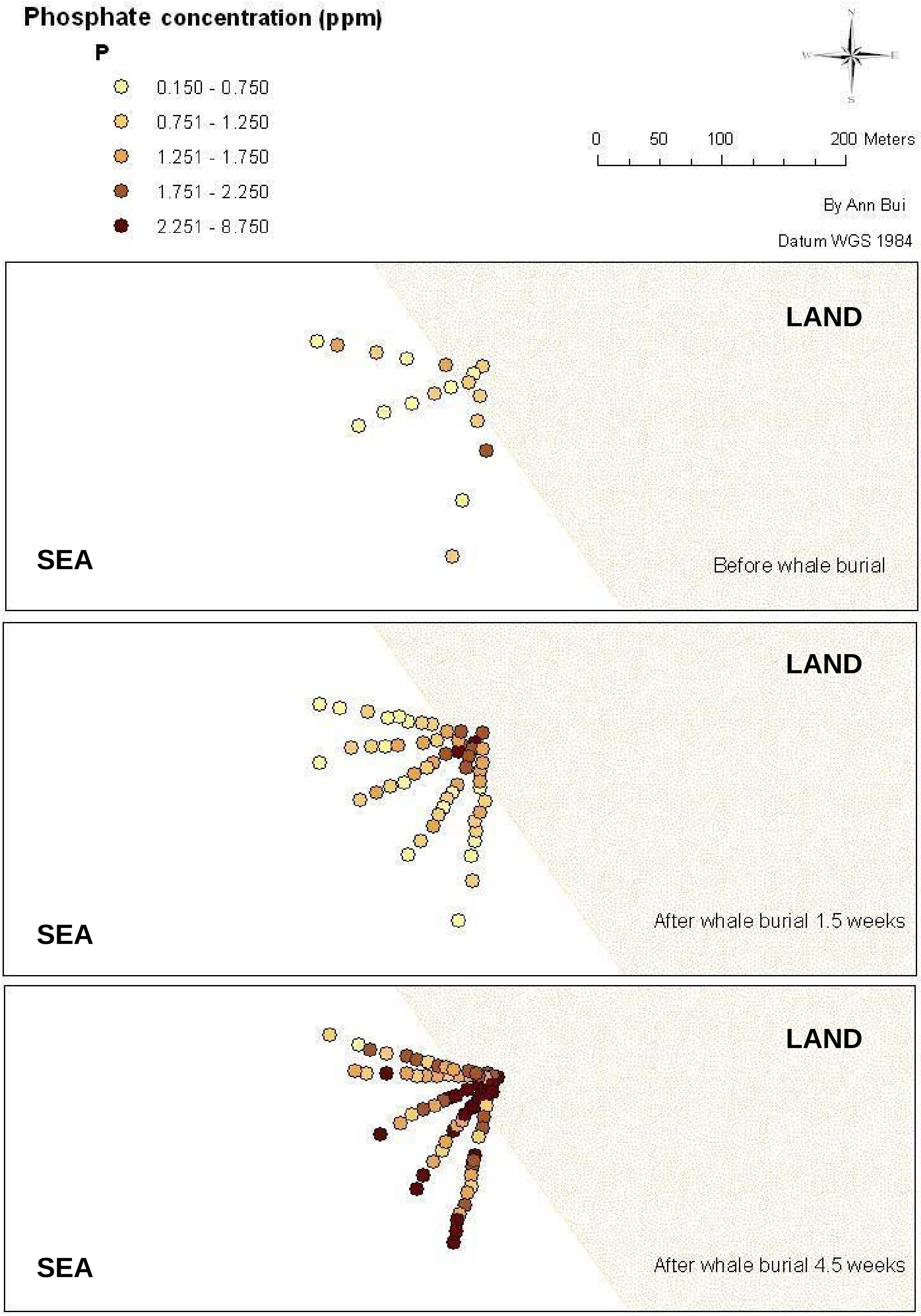

Figure 31: Surface-sand phosphate concentration (ppm) from beginning (before whale burial), 1.5 and 4.5 weeks at Muriwai Beach

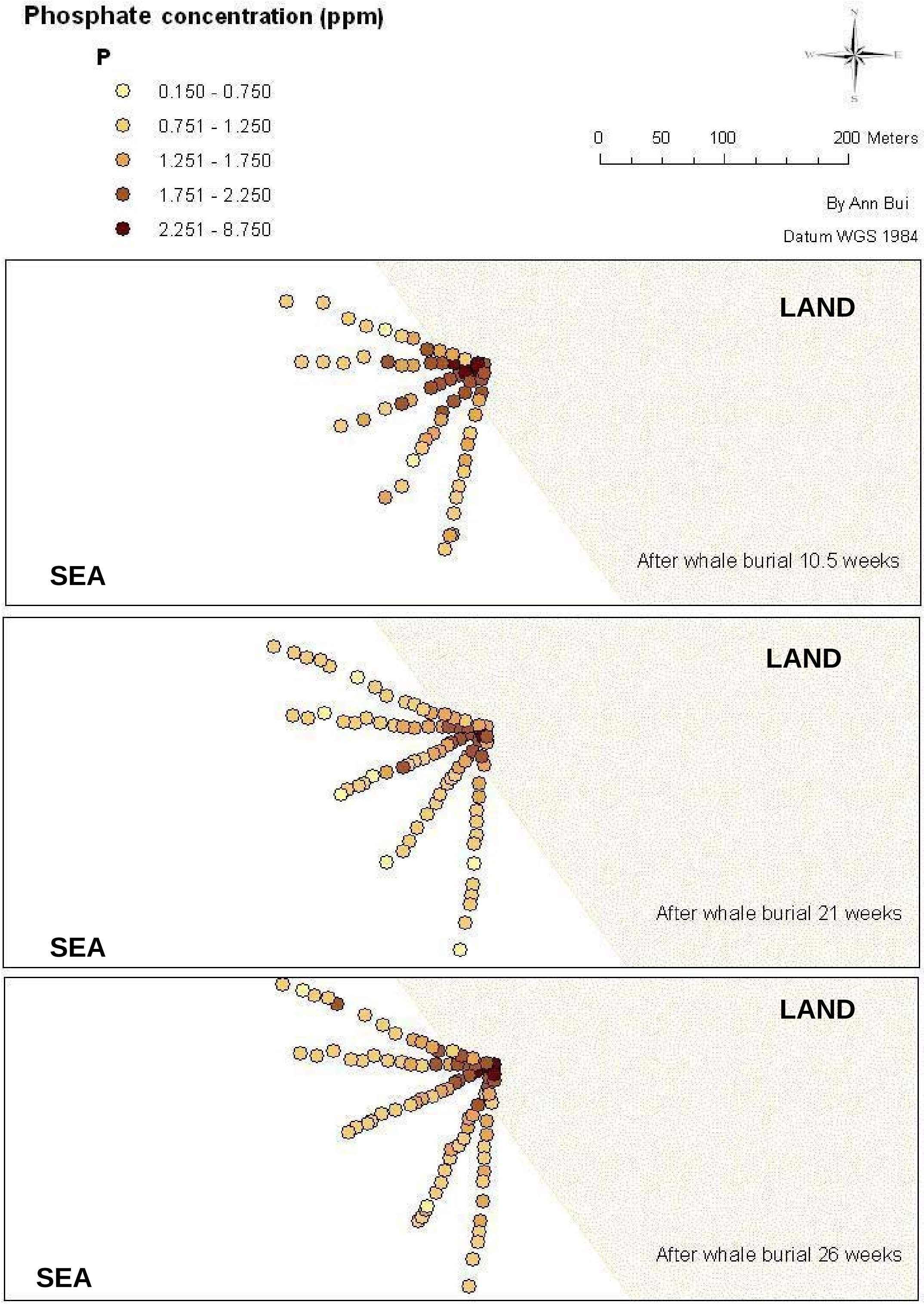

Figure 32: Surface-sand phosphate concentration (ppm) 10.5–26 weeks post whale burial, Muriwai Beach

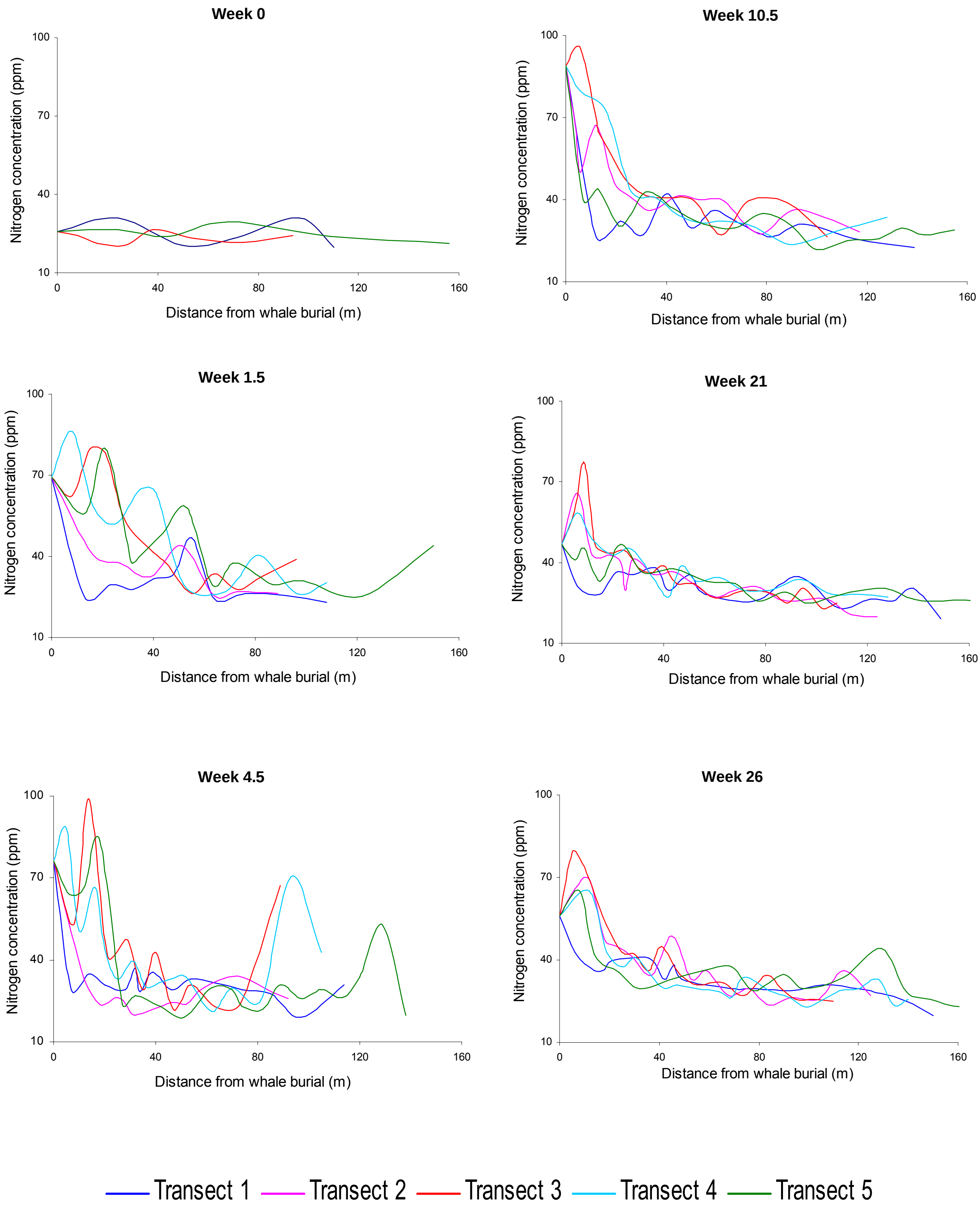

Figure 33: Relationship between surface-sand concentrations of nitrogen at Muriwai Beach with distance from whale burial site over 6 months

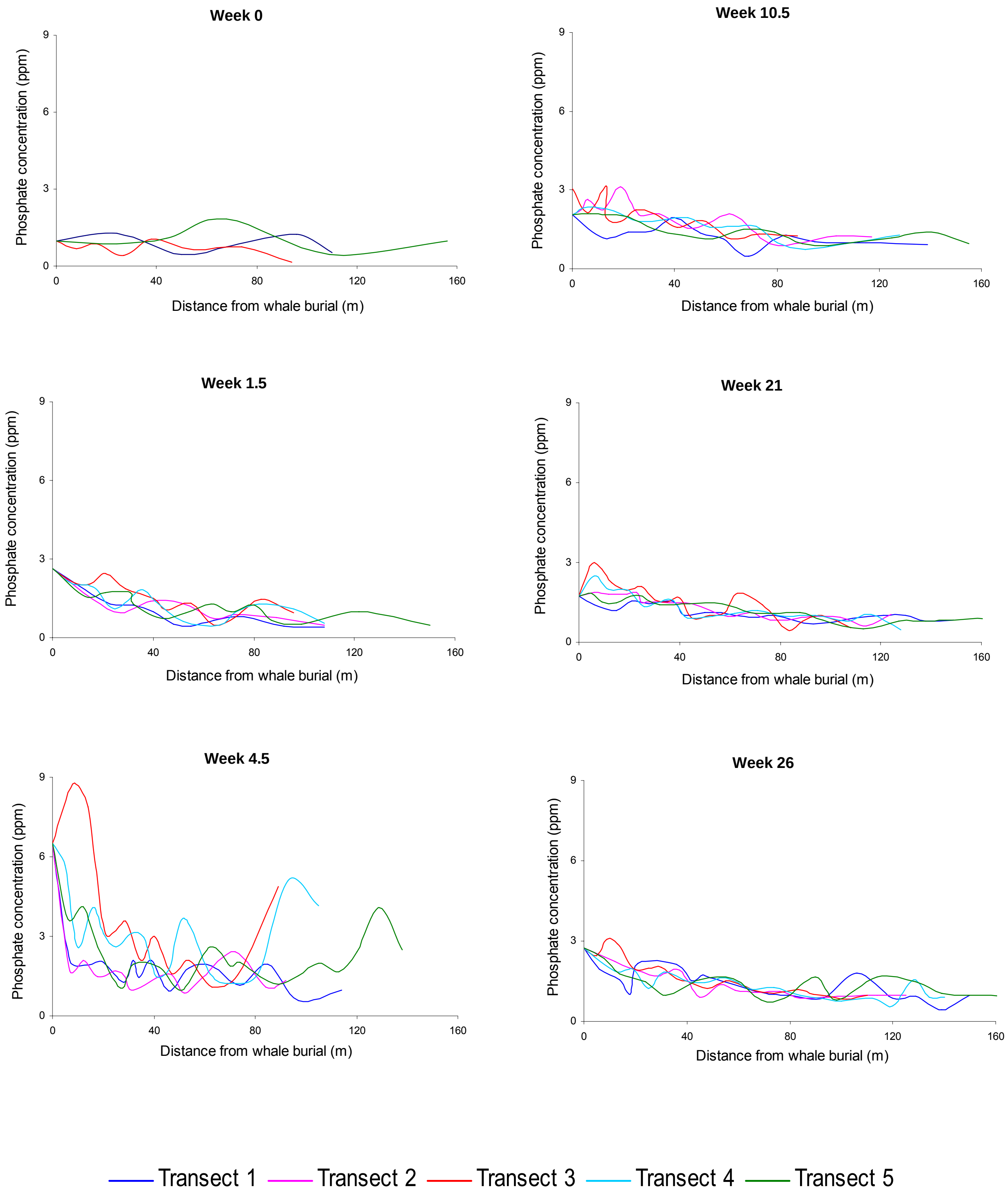

Figure 34: Relationship between surface-sand concentrations of phosphate at Muriwai Beach with distance from whale burial site over 6 months

Table 8: Statistical tests to compare means in concentrations of nitrogen (N) and phosphates (P) for samples at increasing distances from whale burial, Muriwai Beach. (Additional abbreviations: A, ANOVA test; KW, Kruskal-Wallis test; GLM, General linear model; NSD, No significant difference; SD, Significant Difference).

	Chemical	**Normality**		**Equal variance**	**Test used**	**Result**
		Data	Residuals			
Week 0	N	Yes		Yes	A	NSD
	P	Yes		Yes	A	NSD
Week 1.5	N	No		No	KW	SD
	P	Yes		Yes	GLM	SD
Week 4.5	N	No		No	KW	SD
	P	No	No	Yes	KW	SD
Week 10.5	N	No		No	KW	SD
	P	No	No	Yes	KW	SD
Week 21	N	No		No	KW	SD
	P	No		No	KW	SD
Week 26	N	No		No	KW	SD
	P	No	No	Yes	KW	SD

Deep-core sampling

At Muriwai Beach there was no apparent cetacean odor in any sediment core from the surface to 4 m depth above the site of whale burial, or at any other core station running down the shore towards low water (Figure 35). Surface concentrations of nitrogen and phosphate were higher above the site of whale burial than they were in any other samples taken at any distance away from it. Surface concentrations of both nitrogen and phosphates gradually decreased to 1 m depth and then increased at 1.5 m to reach maximum concentrations at 4 m. Further than 24 m from the site of burial, surface and deep-core nitrogen and phosphate concentrations in samples fluctuated between 33 and 41 ppm, and 0.6 and 2.6 ppm, respectively (Figure 36).

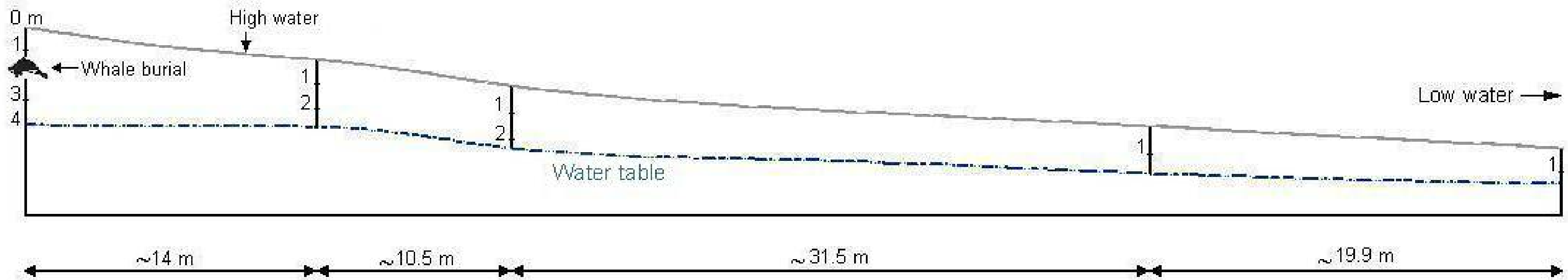

Figure 35: Muriwai beach profile at whale burial, extending to low water

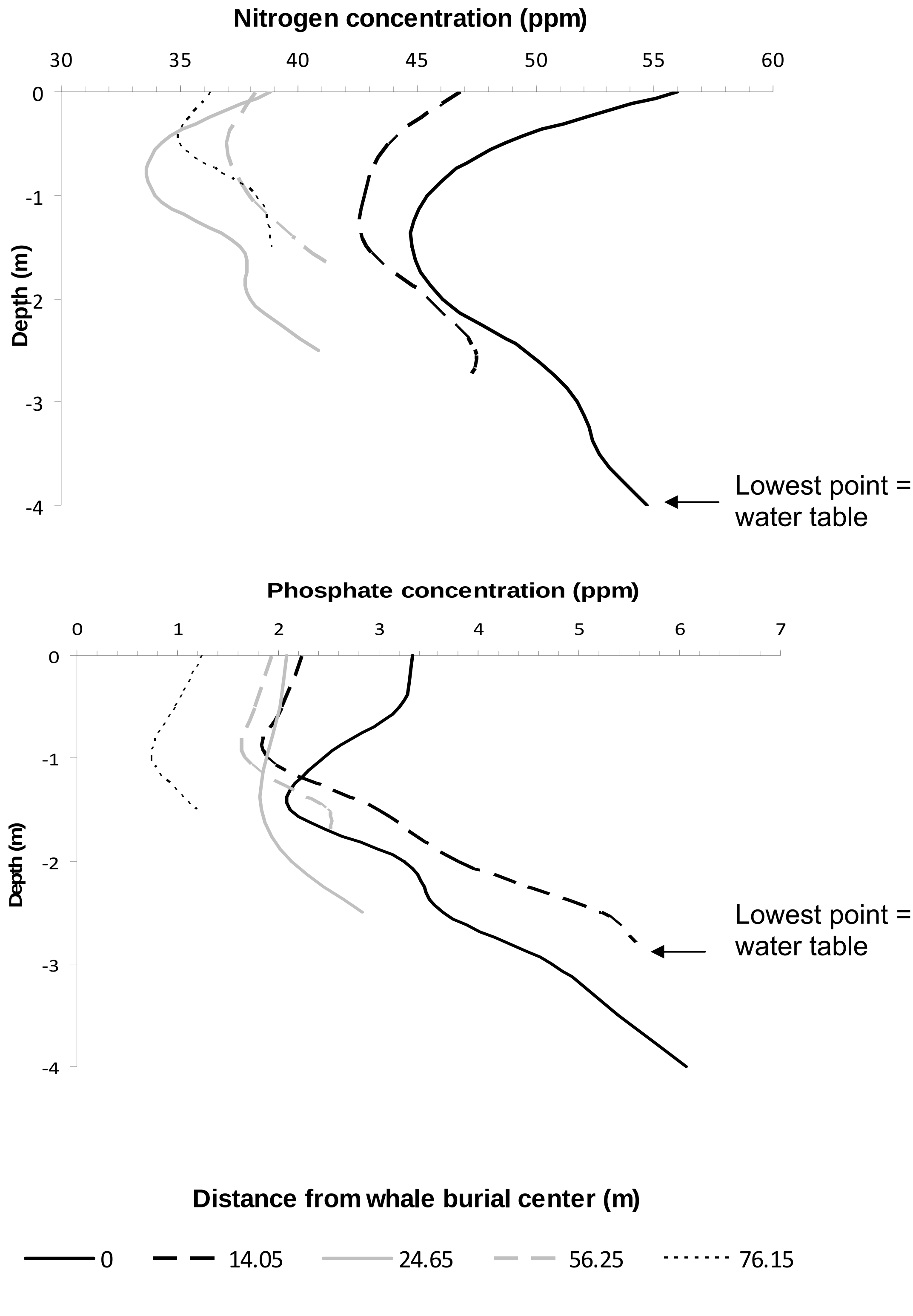

Figure 36: Relationship between nitrogen and phosphate concentrations, sample depth and distance from the site of whale burial, Muriwai Beach

Muriwai Beach faunal survey

Average numbers of species and abundances were used to compare species richness and abundance along transects perpendicular to the whale burial site, extending down the shore, and at three other transects, two to the north and one to the south of the site of whale burial. Almost invariably the number of species and number of individuals was low at extreme high water, and at those site 1 m in vertical drop below high water, then progressively increased along any transect towards low water; nowhere did the number of species per site exceed 5 (Figure 37).

No significant differences were apparent in either species richness or abundance along any transect at any tidal height (0, 1, 2, 3 or 4 m below high water mark). According to species richness index (Table 5) for soft shores Muriwai Beach has *very low* species richness.

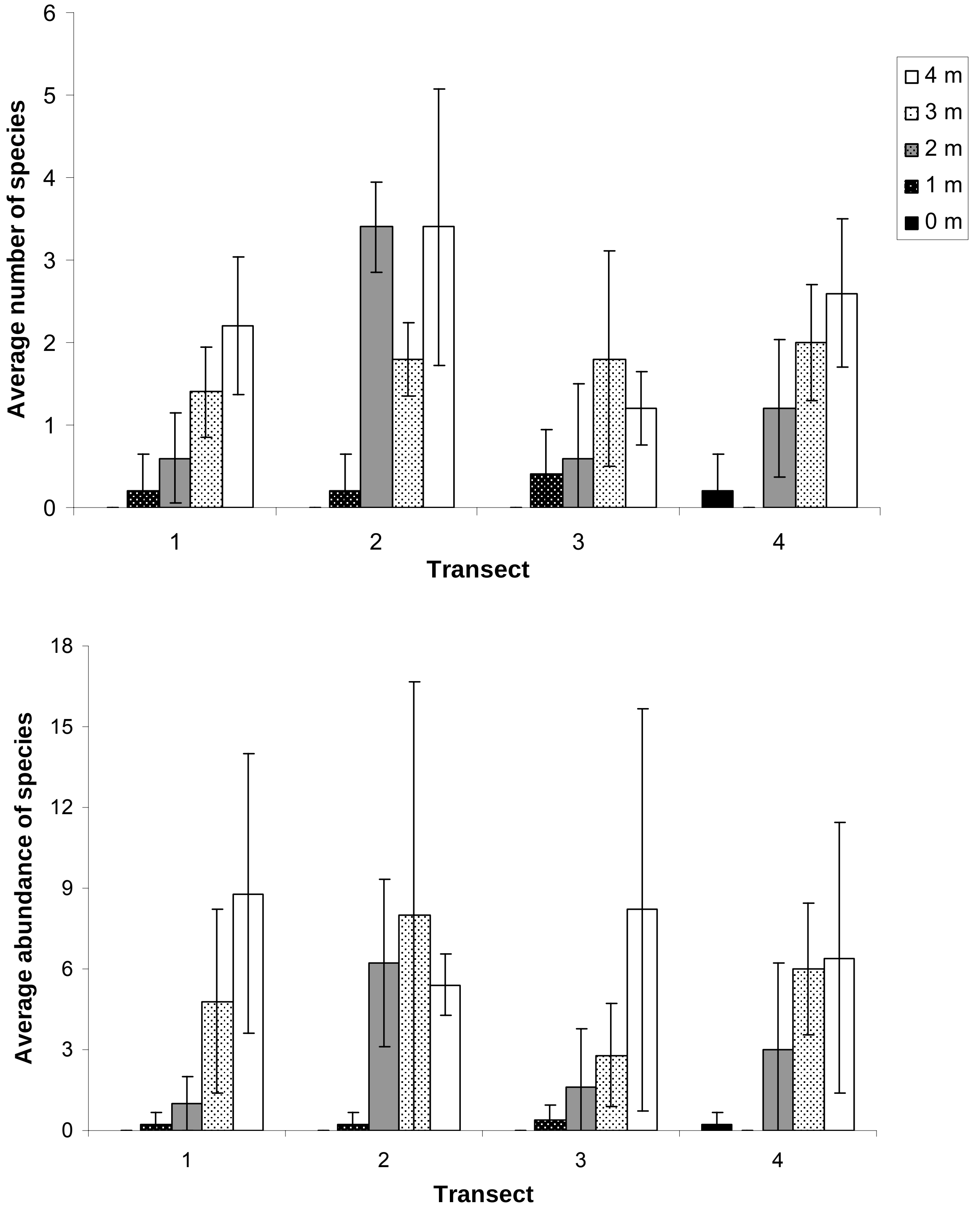

Figure 37: Mean (+/- SD) of species richness (top) and abundance (bottom) at different tidal heights along transects 1–4, Muriwai Beach

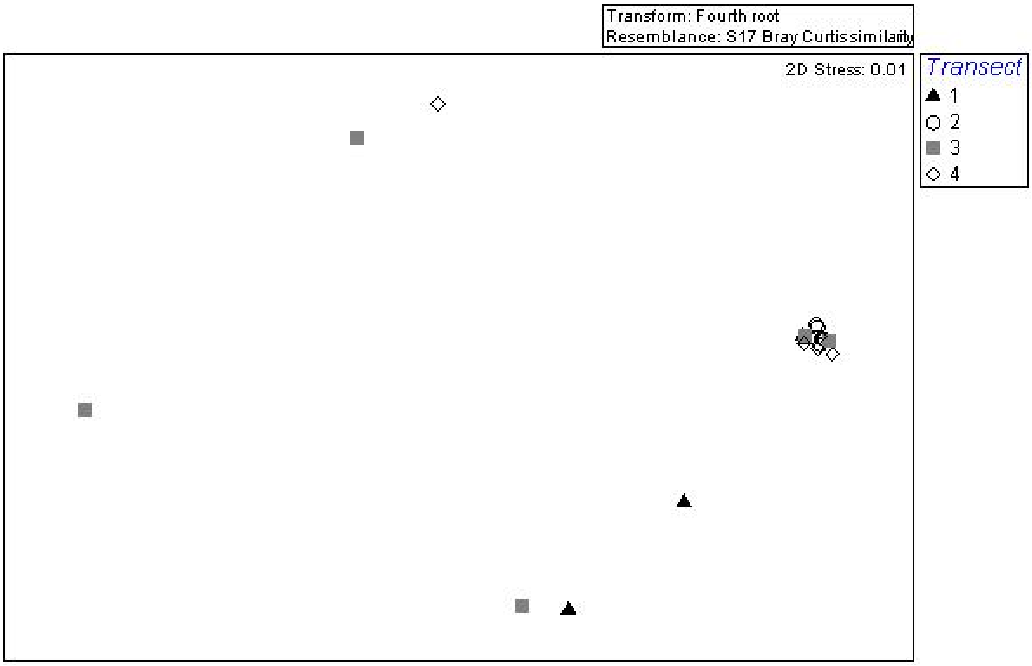

Figure 38: MDS plot of species assemblages at 2 m vertical drop from extreme high water, Muriwai Beach

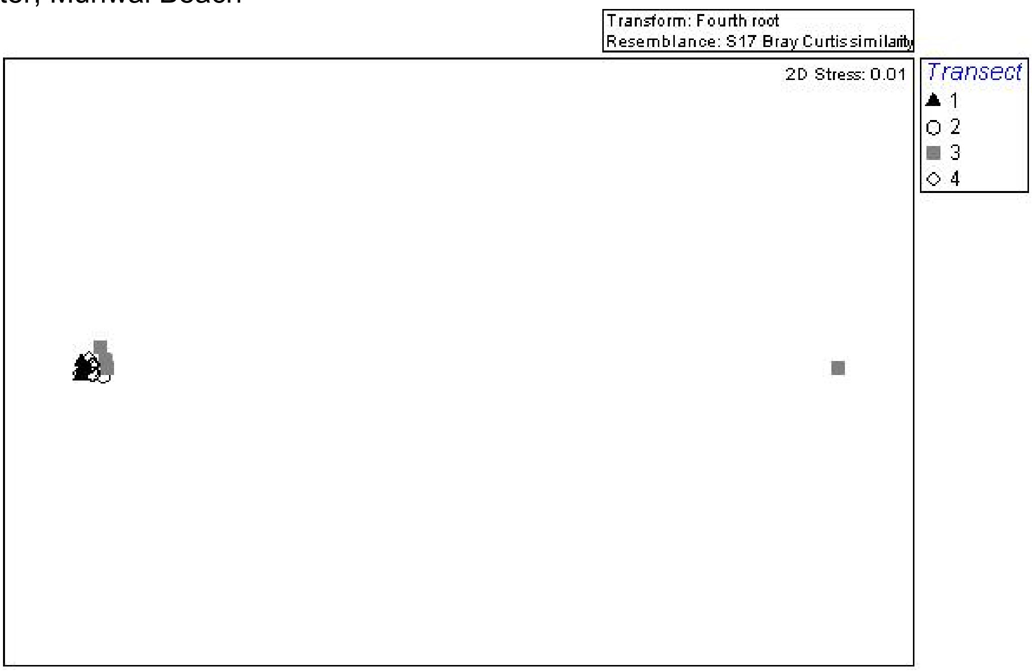

Figure 39: MDS plot of species assemblages at 3 m vertical drop from extreme high water, Muriwai Beach

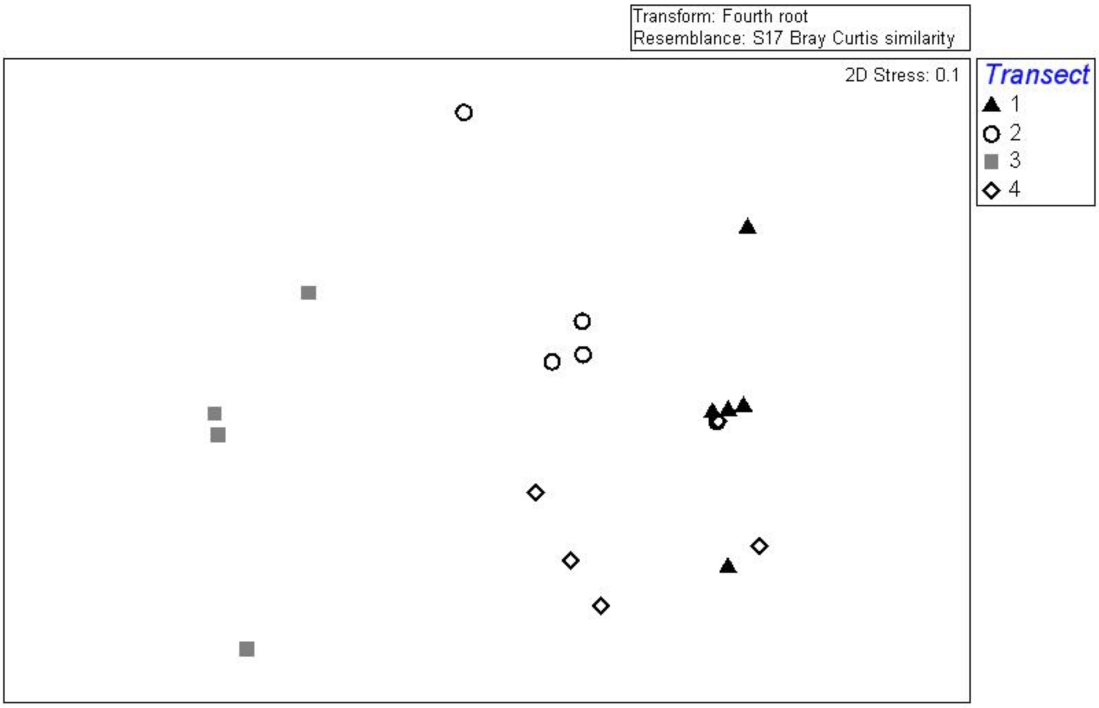

Figure 40: MDS plot of species assemblages at 3 m vertical drop from extreme high water, Muriwai Beach, excluding Transect 3 outlier (from Figure 39)

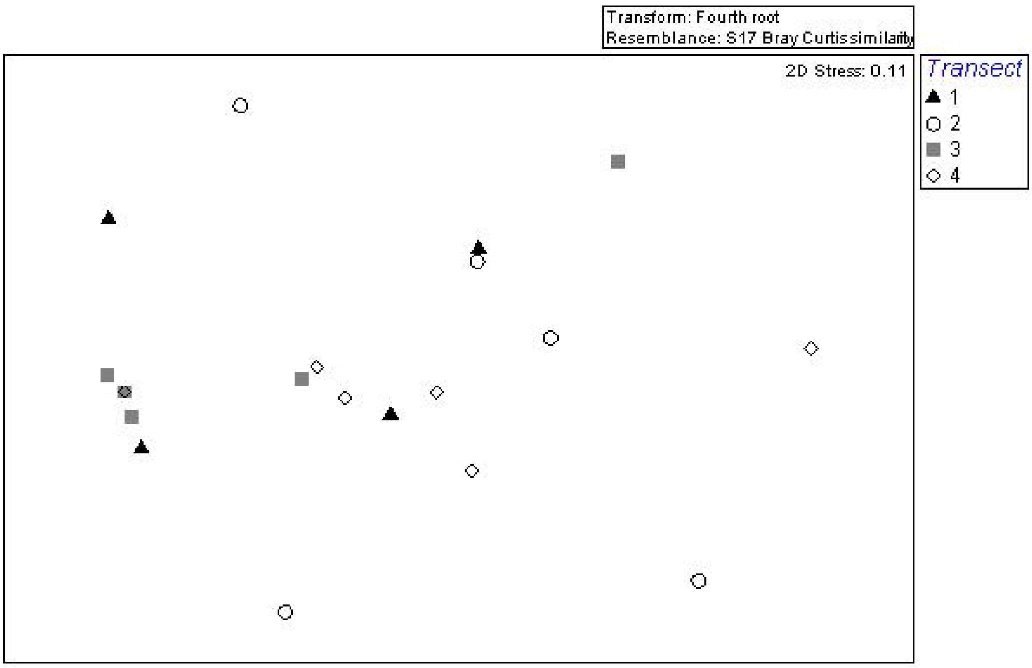

Figure 41: MDS plot of species assemblages at 4 m vertical drop from extreme high water, Muriwai Beach

MDS plots (Figures 38–41) do not reveal any distinctly different species assemblages between any transect and any surveyed tidal height. Due to the low number of species found at extreme high water, and that station along each transect 1 m vertically below it, MDS plots and ANOVA tests could not be performed.

One way ANOVA test for similarities of diversity reveal no significant difference in species richness along any transect, as significance levels were greater than 0.1% (Appendix 3.1, 3.2). At a vertical drop of 3 m from extreme high water along transect 3, one of the five replicate samples was too different from all other sites along this or any other transect, and accordingly MDS plots separate this replicate from all others, clustering all others as similar in species richness (Figure 39). Removing this one replicate, the MDS plot then groups all other samples along this transect (Figure 40), although the grouping is not particularly well defined and is not statistically significant (one way ANOVA to test for similarity in species richness in sample at this distance also revealed no significant difference between transects (significance level <0.01) (Appendix 3.1)). As for other MDS plots, no discernable grouping was apparent between transects for those sites 4 m in vertical drop from extreme high water (Figure 41); ANOVA test similarly revealed no significant difference in species richness between transects (Appendix 3.2).

Discussion

<u>Appropriateness of Motutapu Island for cetacean burials</u>

About 30 soft- or mobile shores occur around Motutapu Island. Of those surveyed shores deemed to be of sufficient size to accommodate a large cetacean, accessible by large vehicles and vessels, and lacking dwellings, residences or significant archaeological sites, Station Bay appears to be the most appropriate. However, sediments at high water in Station Bay already have two large whales buried within them, and given the size small of this beach it could not accommodate many, if any more. At the rate at which cetaceans have been buried on the shores of Motutapu Island in recent years, alternatives for disposal would be exhausted within a few years. Whale burial on Motutapu Island is not a viable long-term option.

Station Bay soft sediments had the highest species richness of all surveyed soft shores on Motutapu Island, but without baseline data on soft-sediment species richness prior to cetacean burial in this beach it cannot be determined whether this is a cause and effect relationship — that is, elevated species richness in these beach sediments could be attributed to cetacean burial. As a complete aside, numerous dead yet articulated (hence recently deceased) horse mussels (*Atrina zelandica*) were observed at extreme low water still buried within sands at Station Bay. Pre-burial surveys are necessary at an area nominated for cetacean burial, as is the case for Station Bay, to ensure the ecological value of an area is fully realised prior to and not compromised as a consequence of cetacean burial. This is even more important for an area like Station Bay, lacking residential dwellings and being remote from areas frequented by visitors, as by virtue of this isolation the beach and associated flora and fauna are more likely to be natural, that is, less likely to have been affected by other forms of anthropogenic disturbance.

Given the small size of beaches and proximity of adjacent intertidal reef, both were surveyed given decomposing carcasses could equally affect rocky shore ecology. The location that had the highest species richness in all sampling locations at Motutapu Island was Home Bay, which, to the best of my knowledge, has not had any cetacean buried within it, and is not considered an appropriate site by DOC to do so.

Of 296 intertidal shores surveyed between Tauranga in the south and Whangarei Heads in the north (Palacio 2008), two of the most species rich occurred on Motutapu Island, and one each on adjacent Browns and Motuihe Islands. Given land usage controls on these islands, such diverse intertidal communities are by default afforded some protection, although none has formal Marine Protected Area status. Of all sites surveyed by Palacio (2008), the most species-rich occurred at Home Bay (Table 9).

On grounds of intertidal species richness alone, no shore on Motutapu Island, or adjacent Browns and Motuihe Islands, is appropriate for cetacean burial, as species richness at these sites is greater than most every other shore surveyed by Palacio (2008). Those on Waiheke Island also hosting elevated levels of species richness would be inappropriate sites for cetacean burial by virtue of their proximity to residential dwellings.

Table 9: Ordination of most species rich sites in intertidal surveys along northeastern New Zealand (Tauranga in the south to Whangarei Heads in the north) (modified from Palacio 2008)

Location	Species Richness
Home Bay (Motutapu Island)	180
McGregor's Bay (Whangarei Heads)	171
Scott Point (Mahurangi)	166
Onetangi, the "Needles" (Waiheke Island)	160
Motuihe Island	157
Whangapoua Beach (Great Barrier Island)	154
Bowentown (Tauranga)	151
McGregors Bay (Whangarei Heads)	151
Langs Beach	150
Port Jackson	149
Browns Island	148
Pauanui Beach	147
Putiki Bay (Waiheke Island)	144
Waikarapupu Bay (Motutapu Island)	142

Beach burial of cetaceans

Health and safety issues must be considered when dealing with cetaceans. Physical contact with a sick animal or handling of its carcass could potentially result in the transfer of disease.

Between 1978 and 2008 a staggering 7,714 carcasses may have been buried in New Zealand beaches. Where are these animals today? Remarkably no signage was erected above either recent site of cetacean burial to inform the public of potentially contaminated sediments in the region, or the existence of a whale buried as shallow as 1 m depth at Pakiri, and 2 m depth at Muriwai. The only discernable trace of whale that would be apparent to an otherwise unsuspecting public at either site was apparent for several weeks only — the lovely aroma of decomposition. The public is probably completely unaware of the magnitude of this problem in the coastal environment around New Zealand. A perimeter must be established around a dead whale, given the potential for transfer of communicable diseases.

Medical counsel should be sought following any cut or other injury or illness caused during or noticed following working on a stranded or otherwise dead whale. Risk of disease transmission can be reduced by wearing gloves, masks, water-proof outerwear to protect clothing from contamination, covering any surface wound on skin when handling with stranding whale or carcass, and washing exposed skin and clothing after work (Geraci & Lounsbury 1993). It is a fact that scientists, DOC personnel and *iwi* dealing with cetacean carcasses are fully clad in protective wear, whereas most recreational users of beaches are scantily clad and barefoot, with little more protection than sun-screen lotion, sunglasses and a hat. Of course the down side to such signposting is exhumation of bodies by the public — the equivalent of grave robbing.

Six weeks following burial of the Gray's beaked whale at Pakiri Beach a group of people partook in an evening of drunken revelry, cooking meat immediately above the whale burial site on an open camp fire. Obviously impaired by alcohol, these louts then proceeded to smash numerous beer bottles, leaving glass shards scattered through the sand around the burial site area (Figure 42). Unknown to these revelers, they risked exposure to viruses, bacteria and/or parasites from the very-shallow-buried decomposing carcass beneath. The length of time that bacteria, viruses and parasites from cetaceans can survive in beach sediments post mortem of their host, the cetacean, is unknown, but at least some poxviruses are tolerant to desiccation, temperature and even disinfectant (Kennedy-Stoskopf 2001). An even greater risk was posed to subsequent users of this stretch of beach, not just because of the amount of broken glass within it, but through infection of any resulting cuts the glass may have caused by these very same pathogens. As a precautionary measure, until the persistence of viruses, bacteria and parasites in beach sediments post-cetacean burial is more fully understood, sites at which cetaceans have been buried should be clearly sign-posted and ring-fenced for a minimum, nominal duration of one year as elevated levels of nitrogen and phosphate persisted for at least six months post burial.

Dune systems are dynamic, in that they are constantly changing, and as is the case on Auckland west coast beaches, eroding, and the latter case exacerbated by the impacts caused by irresponsible use off-road and 4-wheel drive vehicles. It is often within dune systems that cetacean carcasses are buried. Strong winds, storms and erosion could all remove the sand overlying a buried carcass, exposing it to the surface and to the public. The whale can also naturally move through the beach sands as it bloats, in the event it was buried too shallow, as a carcass rich in blubber tends to rise in soft wet sand (Geraci & Lounsbury 1993). Pieces of whale flesh were found lying on the surface of the beach at Station Bay, two years after the last of two whales was buried (pers obsv.). Therefore, it is possible that humans could come into contact with remains of potentially sick whales years after their burial, and risk exposure to pathogens.

Figure 42: Evidence of camp fire and extraneous debris immediately above the site of whale burial (top, arrow), Pakiri Beach 10/04/2008 (AUT)

The physical and biological effects of whale burial reported in this research are considered minor, at least for the two locations at which they were surveyed, as elevated concentrations of nitrogen and phosphates are restricted to a limited radius (less than 40 m) from the site of whale burial, and decrease over the six-month duration of sampling reported herein. As such, burial might appear to be an appropriate, efficient and economical solution to disposing of a cetacean carcass. However, there are a number of unforeseen ill-effects that such burial could have on recreational beach users, and these effects could be persistent.

A limitation of research undertaken in this current study was that cetacean carcasses or proxies (pigs as originally envisaged) could not be left on the surface of beaches, or buried at various depths, enabling the decomposition rates and processes of each monitored. Offshore, isolated islands would prove ideal to undertake such experiments, but all within proximity of Auckland (to Great Barrier Island) host elevated levels of species richness relative to those more accessible to the public, also extensively used for recreational purposes on the mainland. Thus, beach burial of cetaceans around Auckland appears to be an inappropriate course of action, as does that on offshore islands. Alternative strategies should be explored.

<u>Alternatives to cetacean burial/disposal</u>

No previous research like that undertaken in this current study is known. Forensic literature had to be referred to in order to appraise the likely rates of decomposition of mammalian carcasses subject to different environmental conditions. On the basis of this, it is apparent that for a mammalian carcass to decompose rapidly requires an environment that is exposed to air, scavengers, and water. A cetacean carcass left upon the beach is likely to decompose and/or its remains disperse more rapidly than one buried within it, especially if buried at a level of or below the water table (Figure 6). However, given the potential for communicable disease transmission, leaving a cetacean carcass on a beach, especially when death has been attributed to sickness, raises a number of health and safety issues.

For a whale carcass to be left on the surface of a beach the location must be isolated from the public. Around Auckland few such isolated locations exist. Additionally, being isolated means that beach access for heavy machinery is unlikely. Accordingly leaving a carcass on a beach around Auckland is an inappropriate course of action, and is not considered further.

In instances where a large whale strands, or a mass stranding of animals occurs in a public area, burial is the quickest and most economical solution. However, large whales and many whales mean even greater and probably more persistent organic enrichment of beach sediments, and secondarily potentially persistent contaminants and pathogens, exacerbating earlier articulated health and safety issues associated with this disposal option.

The logistics of, and costs associated with transporting a large intact whale (over 5 tons), or large number of smaller whales to a terrestrial site for land-based disposal or land fill would be extraordinary and prohibitive, although this option is viable for small whales to 5 m total length, such as many of the smaller toothed whales that regularly strand on New Zealand beaches. Larger whales, such as sperm or Bryde's whales, to approximately 50 and 20 tons, could not be transported intact, and would have to be cut into manageable pieces (using equipment the likes of diamond ropes); however, spilt entrails would invariably end up fouling roads during transportation, and the heavy machinery and trucks required to achieve this would have to be extensively cleaned after this operation (the lingering smell of whale after attending a stranding event, and conducting an autopsy, can persist for weeks). Towing a whale offshore by vessel, then sinking it, with the assistance of tons of weight, strictly for the purposes of disposal, has (at the time of this thesis) yet to be trialed in New Zealand, although it is understood that in 2008 NIWA sunk a whale at sea in order to monitor ecological succession on the carcass.

Disposal of weighted whales at sea would provide a rich source of energy for myriad fish and invertebrate species. However, this option is likely to prove more expensive than that of beach burial, and the weight required to permanently submerge the carcass is unknown, and will likely vary according to the size and species of whale concerned, its condition, and blubber thickness. A downside to the sea-burial option is that it would deny *iwi* the immediate opportunity to recover whale bone, should this be their intention, and limit researchers access to internal samples.

Other options, including biohazard disposal, incineration, and detonation are not viable for a variety of financial and health and safety reasons, and are not discussed further.

<u>Variation in total N and P, comparing between three beaches</u>

At Pakiri Beach, the whale, a Gray's beaked whale, was recently deceased, most flesh was removed from the carcass by *iwi* for bone-recovery purposes, and the bone and the flesh were buried separately in adjacent manually dug pits approximately 4 m long, 1 m wide, and 1 m deep. The much larger Muriwai whale, an Orca, quite possibly had been dead for a week, and was almost intact (with only its abdomen incised) when buried in a pit dug by heavy machinery above high water at a depth of 2 m. Caution should be

exercised when comparing concentrations of nitrogen and phosphates (as proxies for decomposition rates) between these two locations.
Moreover, Muriwai and Pakiri beaches are two very different environments; iron sands and an extensive intertidal, shallow-sloping platform characterise the former, and white sands and a relatively narrow intertidal platform the latter. The beaches on Motutapu Island bare no resemblance to those of either Muriwai or Pakiri Beach. Accordingly, comparing levels of nitrogen and phosphate in beach sediments at these three locations is of limited value, although both Muriwai and Pakiri Beaches are broadly comparable in that both are surf beaches.

The species and decompositional state of the two whales differed at Muriwai and Pakiri Beach, as did the weather conditions, burial dates, sites, techniques used for burial and depths to which whales were buried, and subsequent monitoring dates and techniques that were imposed by additional access constraints caused by tidal and weather conditions, and the physical sites of whale burial (one in the dunes and one above high water). In retrospect this was not exactly the most controlled of monitoring exercises. Despite these major differences in sites and survey methodologies, background concentrations of nitrogen and phosphate at Pakiri and Muriwai Beaches were similar, 20–30 ppm nitrogen and 0.4–1.2 ppm phosphate, although the maximum background phosphate concentration at Muriwai was greater than that at Pakiri Beach, 8.74 ppm and 3.14 ppm respectively.

Maximum nitrogen concentrations in Muriwai Beach sands, 98.9 ppm, were reached 10.5 weeks after whale burial. This value is greater than that at Pakiri

Beach, where the maximum recorded concentration was 92.8 ppm, reached six weeks post burial. Maximum concentrations of phosphate (8.74 ppm) were recorded at Muriwai Beach 4.5 weeks post burial, whereas the maximum value at Pakiri Beach (3.14 ppm) was recorded 12 weeks post burial. Given aforementioned lack of control over burial location, depth, whale state, pre-burial treatment, and depth to which whales were buried, the reasons for these differences cannot be determined.

The concentration of nitrogen and phosphate in Motutapu Island beach sediments is considerably higher than background levels at either Muriwai or Pakiri beaches. The lowest concentration of nitrogen occurred near Otahuhu Point, but even then this was more than three times background concentrations at either Muriwai or Pakiri Beach. The lowest concentration of phosphate on Motutapu Island was more than four times greater than background levels at either Muriwai or Pakiri Beach. The highest concentrations of these chemicals occurred in muddy soft shores, but they were also very high in Station Bay, where two Bryde's whales, each about 20 tons, had been relatively recently buried.

Other factors could effect concentrations of nitrogen and phosphate in beaches. High concentrations of both were detected at low water on Muriwai Beach 4.5 weeks post whale burial, coinciding with a significant diatom bloom deposit on the sand surface extending kilometers down the beach (Figure 43). Concentrations of these two also could be elevated by other organic matter, such as dead birds, sea weed, seals, wood and other marine life (Figures 8, 9).

Figure 43: Diatom deposits, Muriwai Beach, 4.5 weeks post cetacean burial

Other impacts of burial on beaches

The heavy machinery and vehicles regularly used on beaches for the purposes of digging large holes in the sand to bury whales or transport whale carcass (Figures 3, 5–7, 15, 44) also likely impacts both surface flora and fauna, and infauna in both the dunes, foreshore and along the length of the beach; such machinery also likely contributes to coastal and sand dune erosion. There is still much uncertainty as to the impacts of vehicular traffic on beach flora and fauna in New Zealand (Stephenson 1999), although international literature reveals these impacts can be severe (Leatherman & Godfrey 1979, van der Merwe & van der Merwe 1991, Wilshire *et al*. 1978, and for a comprehensive review, Stephenson 1999).

Figure 44: Excavating hole for Muriwai Orca burial (20/03/2008)

Adverse effects associated with vehicle use in coastal ecosystems, especially in sand dunes, include erosion, destruction of dune vegetation, disturbance of wildlife, introduction of alien species, and alteration of dune ecosystems (Stephenson 1999). Wilshire *et al*. (1978) found off-road vehicles decreased surface strength, increased bulk density 8% and soil moisture (average 23% to 30 cm depth), and reduced 42% organic carbon in sandy soils. Other vehicle impacts have affected the distribution and abundance of an isopod *Tylos capensis* (van der Merwe & van der Merwe 1991), with 10% of animals damaged by approximately 17 vehicle passes, even when they burrowed 20–30 cm below the surface of the sand. After the equivalent of 675 vehicle passes, above-ground biomass of beach grasses was reduced to 25% of initial biomass in the fore-dune track and 15% in the main dune track (Brodhead & Godfrey 1977). On the basis of this, it is likely that the heavy moving and digging equipment used at sites of cetacean stranding is also having an effect on the composition of species in and around sites where it is deployed.

Conclusions

Beaches can be naturally exposed to elevated concentrations of nitrogen and phosphate comparable to those sourced to buried cetacean carcasses, and elevated concentrations of these two need not pose any major risk to the public, especially given concentrations of both on Motutapu Island beaches exceed those levels found over any site of whale burial during those weeks immediately following burial. However, elevated levels above sites of cetacean burial could be symptomatic of something more sinister occurring subsurface.

As a consequence of this research, it is apparent that the shores of Motutapu Island are inappropriate for cetacean burial, and that the Department of Conservation should consider alternative options to manage cetacean disposal problems on the East Coast in the Auckland region.

It is also apparent that research on the persistence and viability of pathogens (viruses, bacteria and parasites) in beach sediments post cetacean burial is required. Such research might allay some health and safety concerns expressed herein. As a bridging solution, until alternative cetacean disposal options have been more fully explored, and the length of time pathogens persist in sediments post burial is determined, signage should be erected around sites of cetacean burial warning public of possible health risks. An exclusion perimeter of no less than 40 m radius from the site of burial is further recommended. As cetaceans represent apex predators they also are prone to accumulating high levels of environmental contaminants, such as PCB's, DDT and dioxin (Ross 2000); the effect of release of elevated levels of these contaminants into beaches and coastal waters, at and near which recreational fishers harvest shellfish and fish, is also worthy of investigation.

On the basis of rates of decomposition of cadavers, it is apparent that cetaceans that are to be buried within beaches should be buried above the water table. What would benefit this research tremendously would have been the opportunity to exhume several cetaceans of various sizes buried at different dates in order to ascertain their state of decomposition, especially those of comparable species, burial depths, and known burial time. Additionally, pre- and post-burial surveys undertaken at regular intervals would enable the effects of cetacean burial over time to be determined; it is suggested to undertake pre-burial intertidal faunal and floral surveys, and then to monitor these monthly for a period of approximately one year.

Finally, environmental impact assessments should be undertaken in areas of recurring cetacean burial. Although the effects on intertidal fauna herein are deemed to be minor, this current research spans a period of 12 months only (from date of burial to the time an intertidal survey was undertaken). Effects could become apparent after several years.

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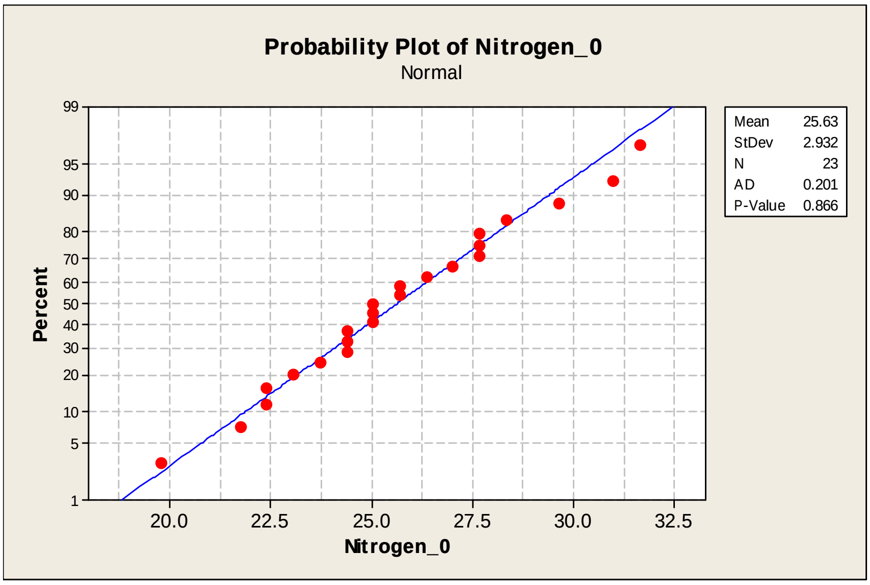
Appendices

Statistical analysis

1. Pakiri Beach chemical analyses

1.1 Week 0



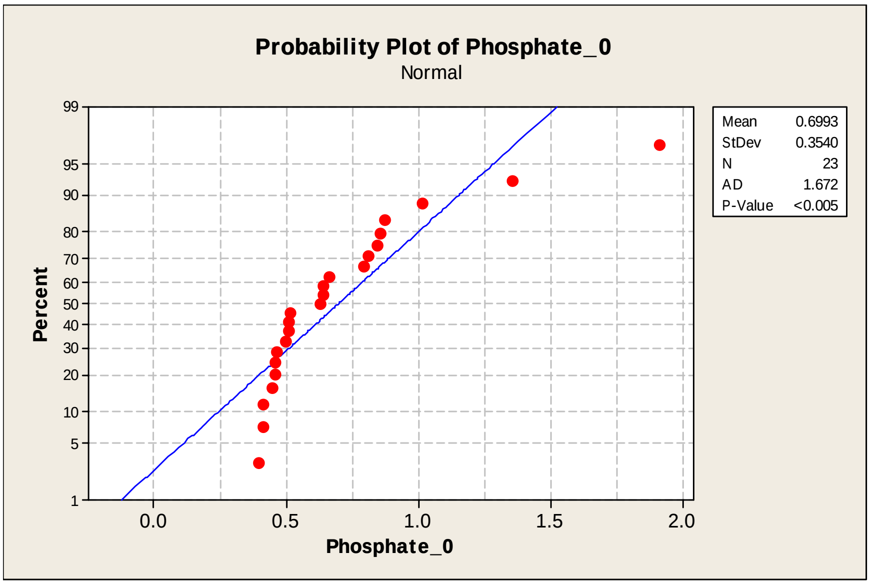
Test for Equal Variances: Nitrogen versus Distance in Week 0

```
95% Bonferroni confidence intervals for standard deviations

Distance_0   N    Lower    StDev    Upper
         1  12  1.72694  2.61728   5.0746
         2   7  1.51550  2.57130   6.9769
         3   4  1.97001  3.89692  21.1945


Bartlett's Test (normal distribution)
Test statistic = 0.92, p-value = 0.632


Levene's Test (any continuous distribution)
Test statistic = 1.27, p-value = 0.302
```

One-way ANOVA: Nitrogen (ppm) versus Distance Week 0

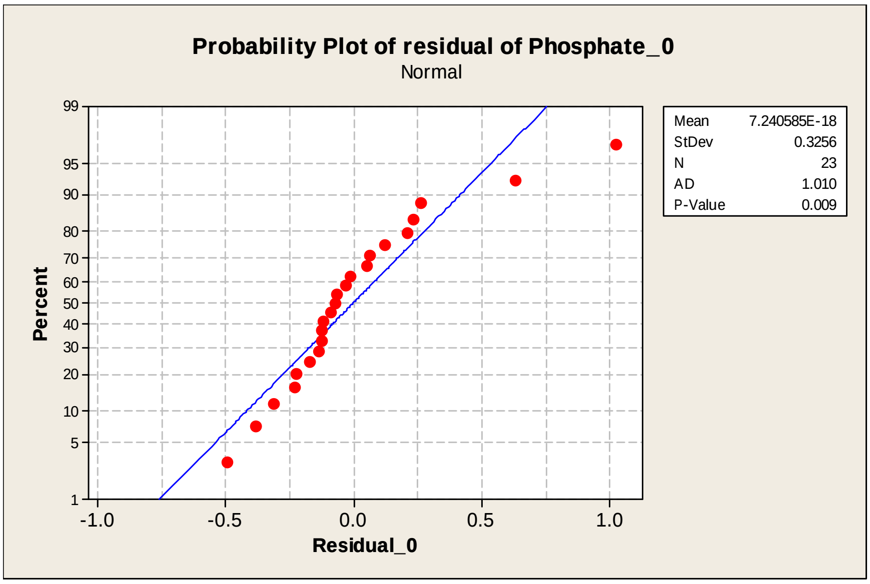
```
Source       DF      SS     MS     F      P
Distance_0    2   28.52  14.26  1.78  0.195
Error        20  160.58   8.03
Total        22  189.10

S = 2.834   R-Sq = 15.08%   R-Sq(adj) = 6.59%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  ----+---------+---------+---------+-----
1      12  24.921  2.617  (--------*-------)
2       7  25.501  2.571  (-----------*----------)
3       4  27.995  3.897           (-------------*-------------)
                          ----+---------+---------+---------+-----
                           24.0      26.0      28.0      30.0
```

Pooled StDev = 2.834



Test for Equal Variances: Phosphate_0 versus Distance_0

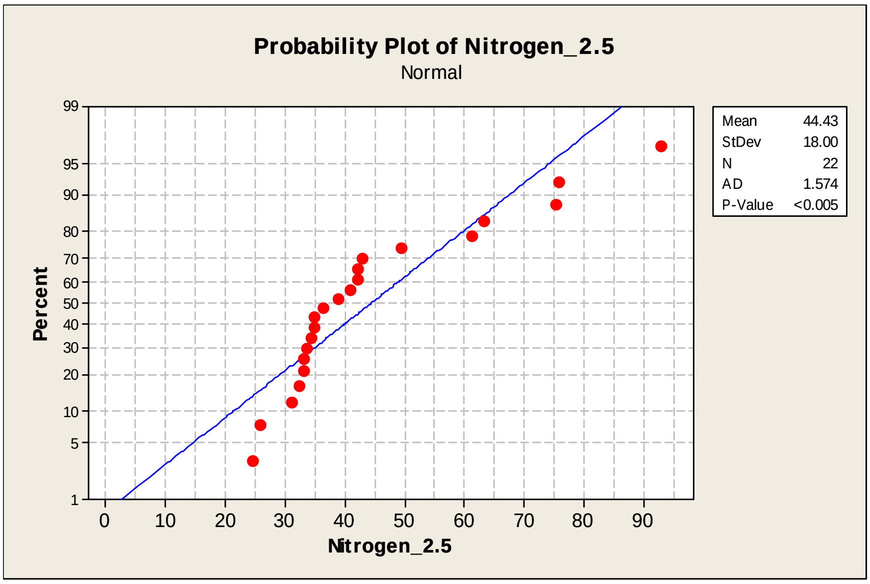
```
95% Bonferroni confidence intervals for standard deviations

Distance_0   N     Lower     StDev    Upper
         1  12  0.104036  0.157672  0.30571
         2   7  0.295018  0.500550  1.35818
         3   4  0.217643  0.430525  2.34153


Bartlett's Test (normal distribution)
Test statistic = 10.12, p-value = 0.006


Levene's Test (any continuous distribution)
Test statistic = 1.42, p-value = 0.265
```



Kruskal-Wallis Test: Phosphate_0 versus Distance_0

```
Kruskal-Wallis Test on Phosphate_0

Distance_0    N  Median  Ave Rank      Z
1            12  0.5102      10.1  -1.38
2             7  0.8561      15.5   1.64
3             4  0.5663      11.5  -0.16
Overall      23              12.0

H = 2.80  DF = 2  P = 0.246
H = 2.80  DF = 2  P = 0.246  (adjusted for ties)

* NOTE * One or more small samples
```

1.2 Week 2.5



Test for Equal Variances: Nitrogen_2.5 versus Distance_2.5

95% Bonferroni confidence intervals for standard deviations

Distance_2.5	N	Lower	StDev	Upper
1	12	14.0951	21.3618	41.4180
2	5	2.2145	4.0977	15.7717
3	5	1.9498	3.6078	13.8862

Bartlett's Test (normal distribution)
Test statistic = 16.06, p-value = 0.000

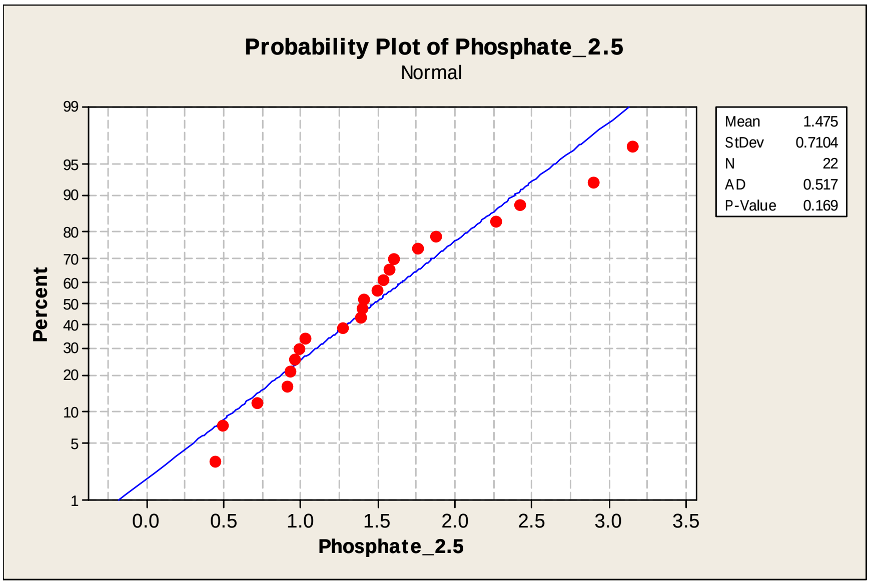
Levene's Test (any continuous distribution)
Test statistic = 6.12, p-value = 0.009

Kruskal-Wallis Test: Nitrogen_2.5 versus Distance_2.5

Kruskal-Wallis Test on Nitrogen_2.5

Distance_2.5	N	Median	Ave Rank	Z
1	12	45.78	13.8	1.78
2	5	40.84	12.2	0.27
3	5	32.94	5.4	-2.39
Overall	22		11.5	

H = 5.91 DF = 2 P = 0.052
H = 5.92 DF = 2 P = 0.052 (adjusted for ties)



Test for Equal Variances: Phosphate_2.5 versus Distance_2.5

95% Bonferroni confidence intervals for standard deviations

Distance_2.5	N	Lower	StDev	Upper
1	12	0.541375	0.820483	1.59082
2	5	0.178519	0.330326	1.27139
3	5	0.258502	0.478323	1.84102

Bartlett's Test (normal distribution)
Test statistic = 4.03, p-value = 0.133

Levene's Test (any continuous distribution)
Test statistic = 1.80, p-value = 0.193

One-way ANOVA: Phosphate_2.5 versus Distance_2.5

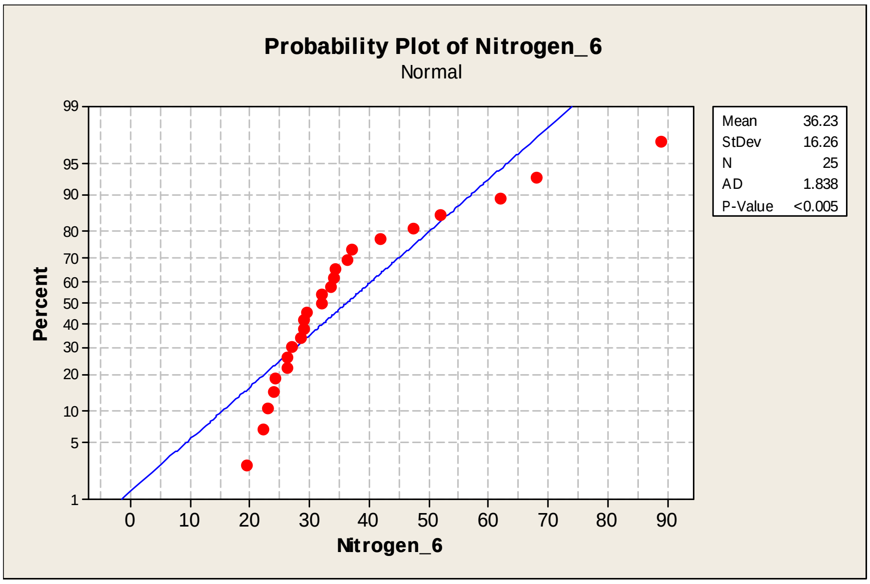
Source	DF	SS	MS	F	P
Distance_2.5	2	1.842	0.921	2.00	0.163
Error	19	8.757	0.461		
Total	21	10.599			

S = 0.6789   R-Sq = 17.38%   R-Sq(adj) = 8.68%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level   N    Mean   StDev  --+---------+---------+---------+-------
1      12  1.7228  0.8205                    (-------*--------)
2       5  1.3249  0.3303        (-----------*------------)
3       5  1.0294  0.4783  (------------*-----------)
                           --+---------+---------+---------+-------
                           0.50      1.00      1.50      2.00
```

Pooled StDev = 0.6789

1.3 Week 6



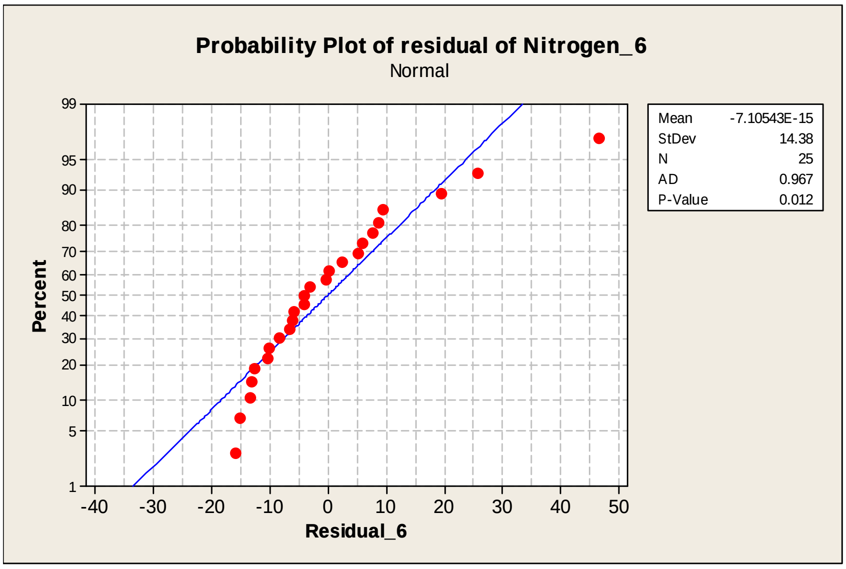
Test for Equal Variances: Nitrogen_6 versus Distance_6

95% Bonferroni confidence intervals for standard deviations

Distance_6	N	Lower	StDev	Upper
1	13	12.5064	18.6801	34.9377
2	7	2.6890	4.5624	12.3794
3	5	3.6440	6.7428	25.9523

Bartlett's Test (normal distribution)
Test statistic = 12.35, p-value = 0.002

Levene's Test (any continuous distribution)
Test statistic = 2.29, p-value = 0.125

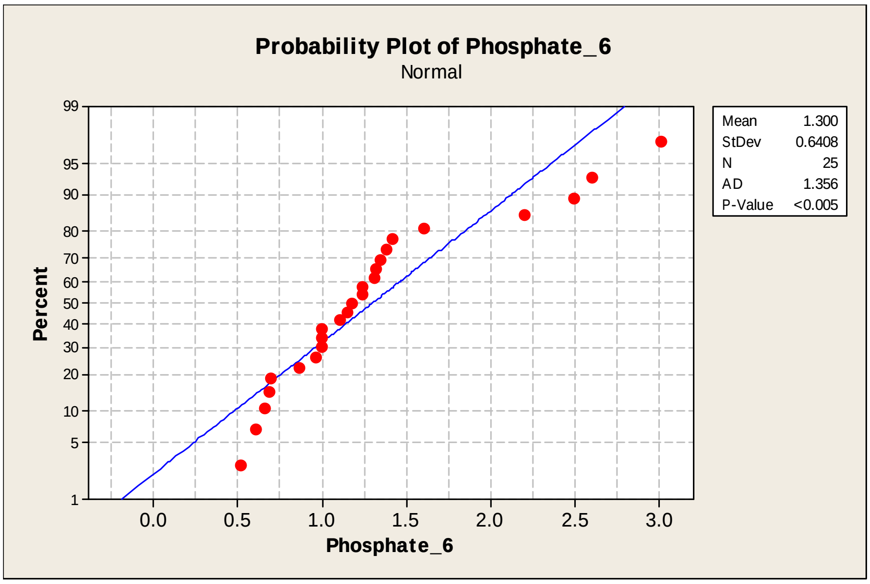


Kruskal-Wallis Test: Nitrogen_6 versus Distance_6

Kruskal-Wallis Test on Nitrogen_6

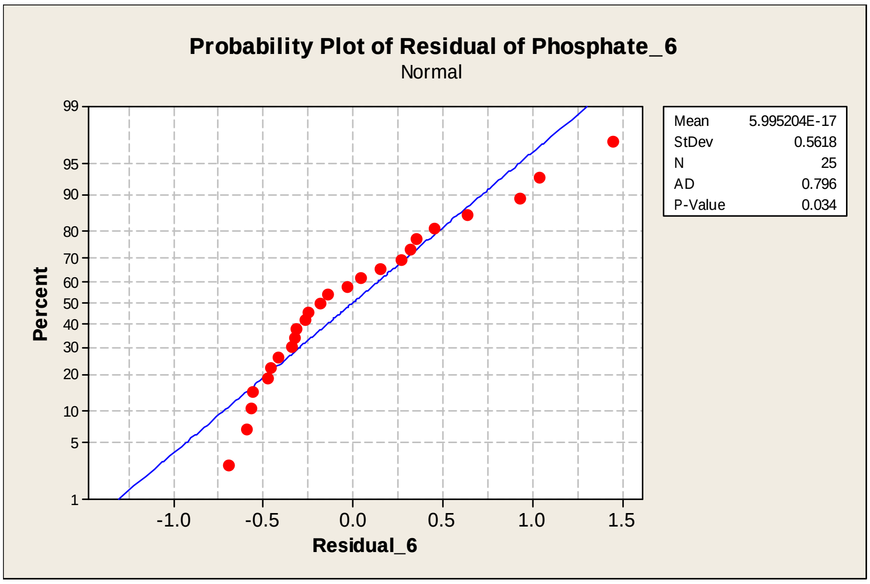
Distance_6	N	Median	Ave Rank	Z
1	13	36.23	17.3	3.05
2	7	27.01	7.6	-2.30
3	5	24.11	9.4	-1.22
Overall	25		13.0	

H = 9.46   DF = 2   P = 0.009



Test for Equal Variances: Phosphate_6 versus Distance_6

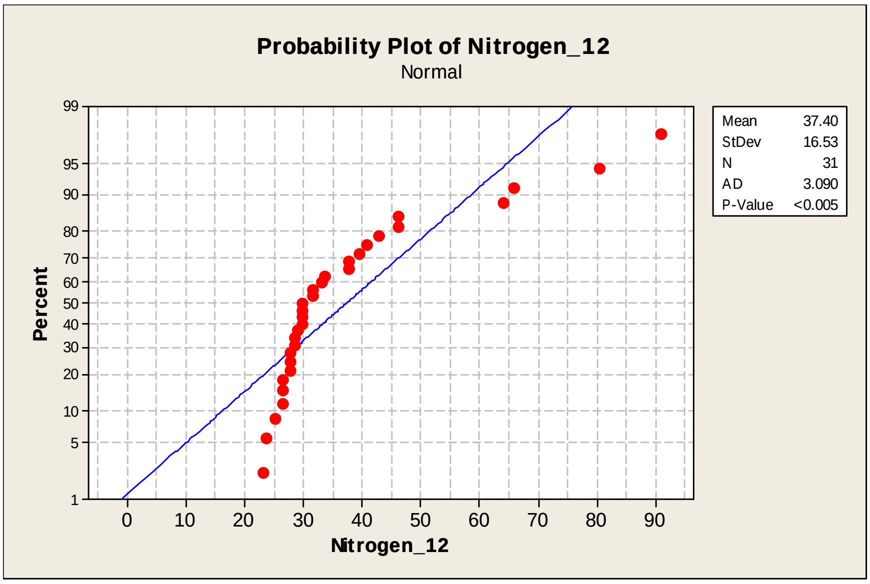
```
95% Bonferroni confidence intervals for standard deviations

Distance_6   N     Lower     StDev    Upper
         1  13  0.467576  0.698392  1.30622
         2   7  0.133959  0.227284  0.61671
         3   5  0.207368  0.383708  1.47685


Bartlett's Test (normal distribution)
Test statistic = 7.50, p-value = 0.023


Levene's Test (any continuous distribution)
Test statistic = 1.62, p-value = 0.221
```



Kruskal-Wallis Test: Phosphate_6 versus Distance_6

```
Kruskal-Wallis Test on Phosphate_6

Distance_6    N  Median  Ave Rank      Z
1            13  1.3759      17.1   2.88
2             7  0.9916       7.4  -2.36
3             5  1.1448      10.2  -0.95
Overall      25              13.0

H = 8.72  DF = 2  P = 0.013
```

1.4 Week 12



Test for Equal Variances: Nitrogen_12 versus Distance_12

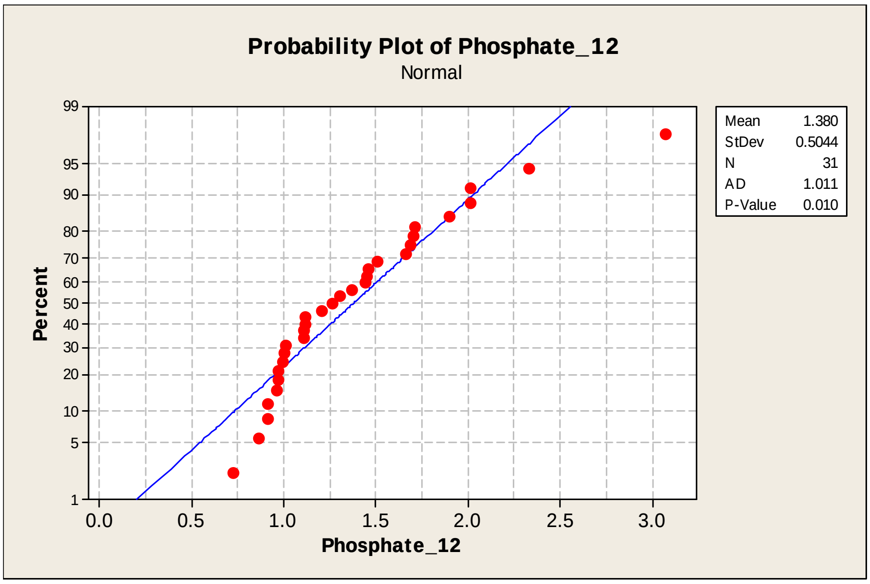
```
95% Bonferroni confidence intervals for standard deviations

Distance_12   N    Lower    StDev    Upper
          1  16  13.8727  19.9981  34.4551
          2   9   3.0175   4.8404  10.9615
          3   6   1.5442   2.7212   8.5014


Bartlett's Test (normal distribution)
Test statistic = 24.73, p-value = 0.000


Levene's Test (any continuous distribution)
Test statistic = 4.79, p-value = 0.016
```

Kruskal-Wallis Test: Nitrogen_12 versus Distance_12

Kruskal-Wallis Test on Nitrogen_12

Distance_12	N	Median	Ave Rank	Z
1	16	40.18	20.4	2.81
2	9	28.98	12.4	-1.41
3	6	27.99	9.6	-1.92
Overall	31		16.0	

```
H = 8.22  DF = 2  P = 0.016
H = 8.26  DF = 2  P = 0.016  (adjusted for ties)
```



Test for Equal Variances: Phosphate_12 versus Distance_12

95% Bonferroni confidence intervals for standard deviations

Distance_12	N	Lower	StDev	Upper
1	16	0.422335	0.608817	1.04894
2	9	0.156883	0.251659	0.56990
3	6	0.063261	0.111480	0.34828

```
Bartlett's Test (normal distribution)
Test statistic = 15.45, p-value = 0.000


Levene's Test (any continuous distribution)
Test statistic = 4.97, p-value = 0.014
```

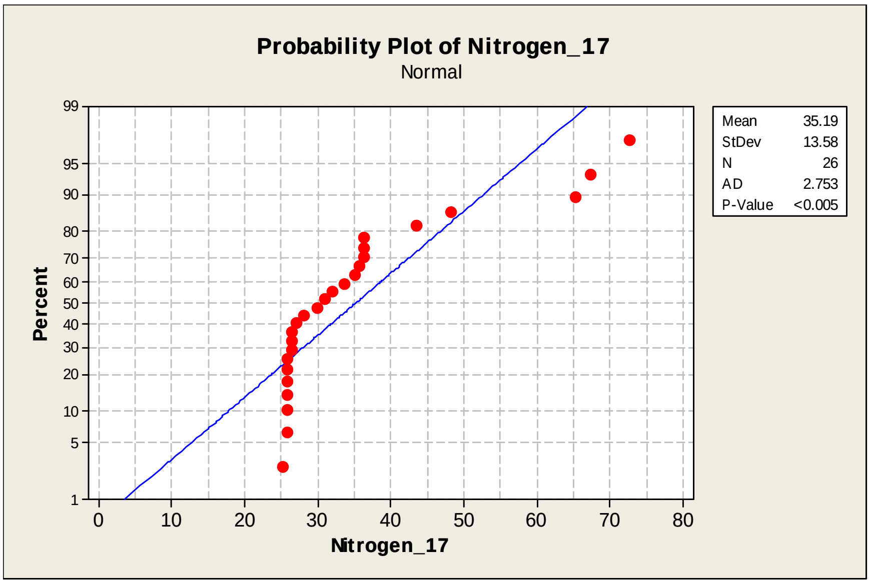
Kruskal-Wallis Test: Phosphate_12 versus Distance_12

Kruskal-Wallis Test on Phosphate_12

Distance_12	N	Median	Ave Rank	Z
1	18	1.4828	19.2	2.30
2	7	1.1149	13.9	-0.71
3	6	0.9828	8.9	-2.13
Overall	31		16.0	

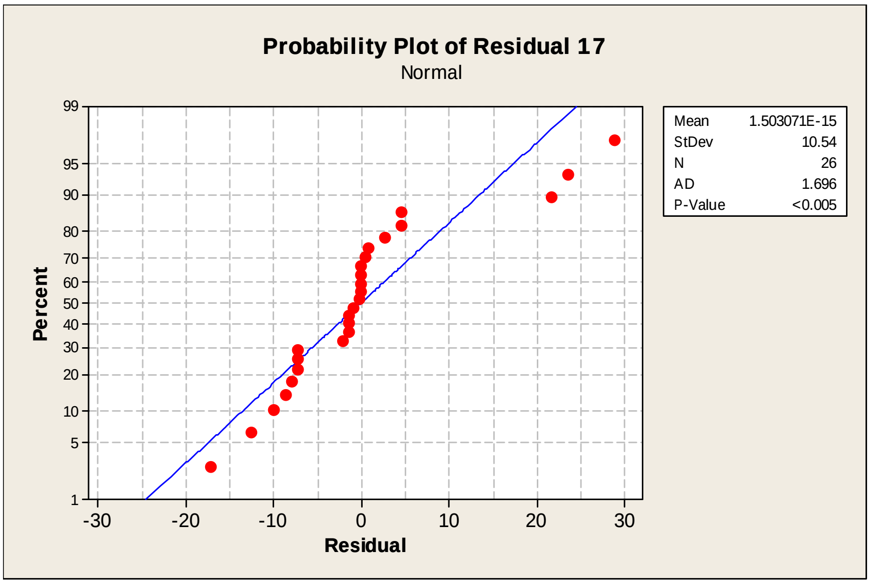
```
H = 6.25  DF = 2  P = 0.044
H = 6.25  DF = 2  P = 0.044  (adjusted for ties)
```

1.5 Week 17



Test for Equal Variances: Nitrogen_17 versus Distance_17

```
95% Bonferroni confidence intervals for standard deviations

Distance_17    N     Lower     StDev     Upper
          1   13   10.1108   15.1019   28.2454
          2    9    1.4090    2.2602    5.1185
          3    4    0.1665    0.3294    1.7913


Bartlett's Test (normal distribution)
Test statistic = 35.75, p-value = 0.000


Levene's Test (any continuous distribution)
Test statistic = 3.12, p-value = 0.063
```



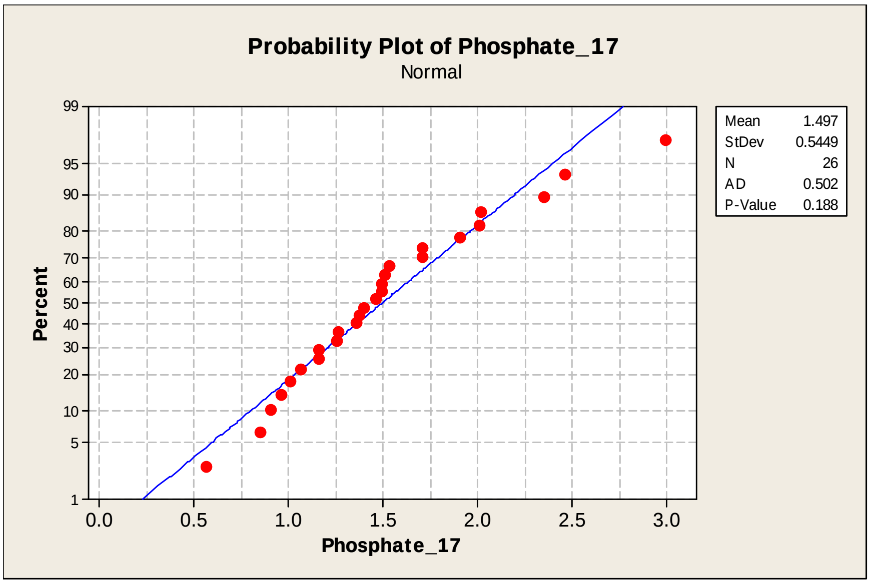
Kruskal-Wallis Test: Nitrogen_17 versus Distance_17

Kruskal-Wallis Test on Nitrogen_17

Distance_17	N	Median	Ave Rank	Z
1	13	36.23	19.5	4.03
2	9	26.35	8.3	-2.53
3	4	25.69	5.6	-2.24
Overall	26		13.5	

H = 16.54 DF = 2 P = 0.000
H = 16.79 DF = 2 P = 0.000 (adjusted for ties)

* NOTE * One or more small samples



Test for Equal Variances: Phosphate_17 versus Distance_17

95% Bonferroni confidence intervals for standard deviations

Distance_17	N	Lower	StDev	Upper
1	13	0.326274	0.487338	0.911478
2	9	0.102576	0.164545	0.372624
3	4	0.089716	0.177468	0.965214

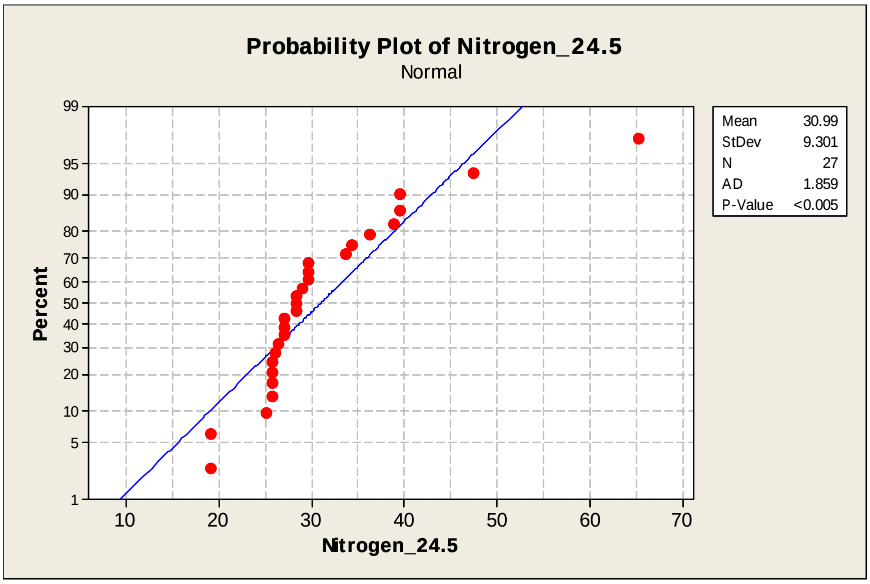
Bartlett's Test (normal distribution)
Test statistic = 10.02, p-value = 0.007

Levene's Test (any continuous distribution)
Test statistic = 2.66, p-value = 0.092

General Linear Model: Phosphate_17 versus Distance_17

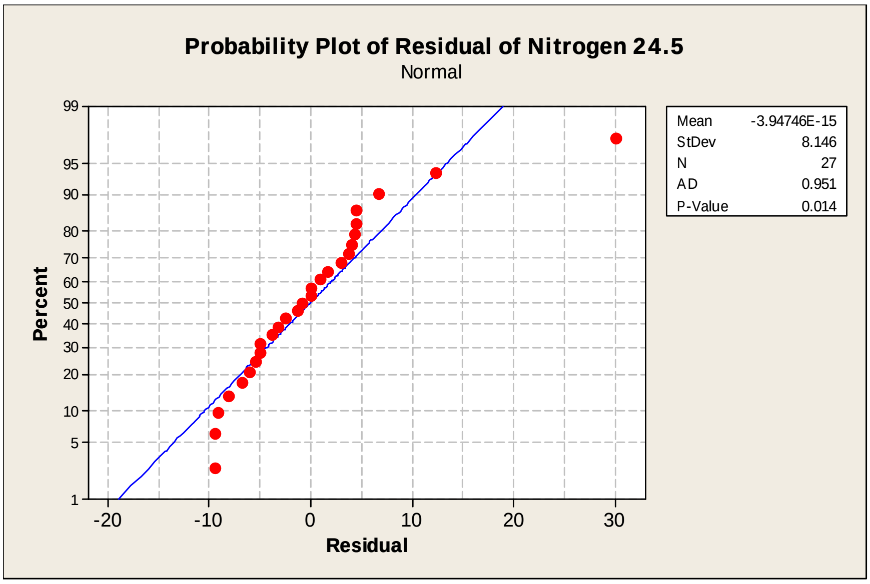
```
Factor       Type   Levels  Values
Distance_17  fixed       3  1, 2, 3


Analysis of Variance for Phosphate_17, using Adjusted SS for Tests

Source       DF  Seq SS  Adj SS  Adj MS      F      P
Distance_17   2  4.2605  4.2605  2.1302  15.50  0.000
Error        23  3.1611  3.1611  0.1374
Total        25  7.4215


S = 0.370726   R-Sq = 57.41%   R-Sq(adj) = 53.70%


Unusual Observations for Phosphate_17

Obs  Phosphate_17      Fit   SE Fit  Residual  St Resid
 12       2.99160  1.87674  0.10282   1.11486      3.13 R

R denotes an observation with a large standardized residual.


Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Phosphate_17
All Pairwise Comparisons among Levels of Distance_17
Distance_17 = 1  subtracted from:

Distance_17   Lower  Center    Upper   --+---------+---------+---------+----
2            -1.029  -0.627  -0.2241             (-------*--------)
3            -1.588  -1.058  -0.5269   (----------*---------)
                                       --+---------+---------+---------+----
                                       -1.50     -1.00     -0.50      0.00


Distance_17 = 2  subtracted from:

Distance_17    Lower   Center   Upper   --+---------+---------+---------+---
-
3            -0.9887  -0.4310  0.1266              (----------*-----------)
                                        --+---------+---------+---------+---
-
                                        -1.50     -1.00     -0.50      0.00


Tukey Simultaneous Tests
Response Variable Phosphate_17
All Pairwise Comparisons among Levels of Distance_17
Distance_17 = 1  subtracted from:

             Difference       SE of           Adjusted
Distance_17    of Means  Difference  T-Value   P-Value
2                -0.627      0.1608   -3.897    0.0020
3                -1.058      0.2120   -4.989    0.0001


Distance_17 = 2  subtracted from:

             Difference       SE of           Adjusted
Distance_17    of Means  Difference  T-Value   P-Value
3               -0.4310      0.2228   -1.935    0.1517
```

1.6 Week 24.5



Test for Equal Variances: Nitrogen_24.5 versus Distance_24.5

```
95% Bonferroni confidence intervals for standard deviations

Distance_24.5    N     Lower     StDev     Upper
            1   13   7.61266   11.3706   21.2667
            2    8   2.22815    3.6664    8.9795
            3    6   2.26446    3.9904   12.4667


Bartlett's Test (normal distribution)
Test statistic = 11.49, p-value = 0.003


Levene's Test (any continuous distribution)
Test statistic = 1.77, p-value = 0.192
```

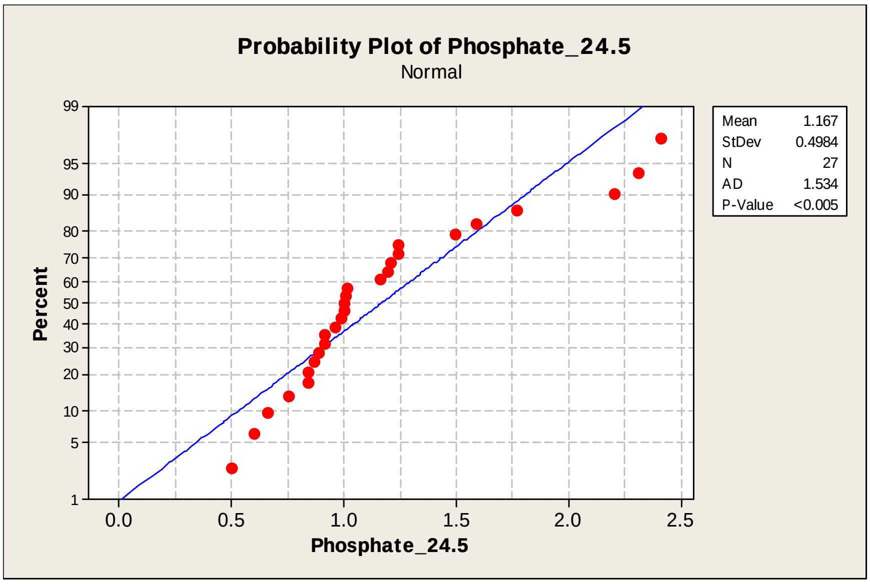


Kruskal-Wallis Test: Nitrogen_24.5 versus Distance_24.5

Kruskal-Wallis Test on Nitrogen_24.5

Distance_24.5	N	Median	Ave Rank	Z
1	13	29.64	17.2	2.04
2	8	28.98	14.7	0.29
3	6	25.36	6.1	-2.77
Overall	27		14.0	

H = 8.18 DF = 2 P = 0.017
H = 8.24 DF = 2 P = 0.016 (adjusted for ties)



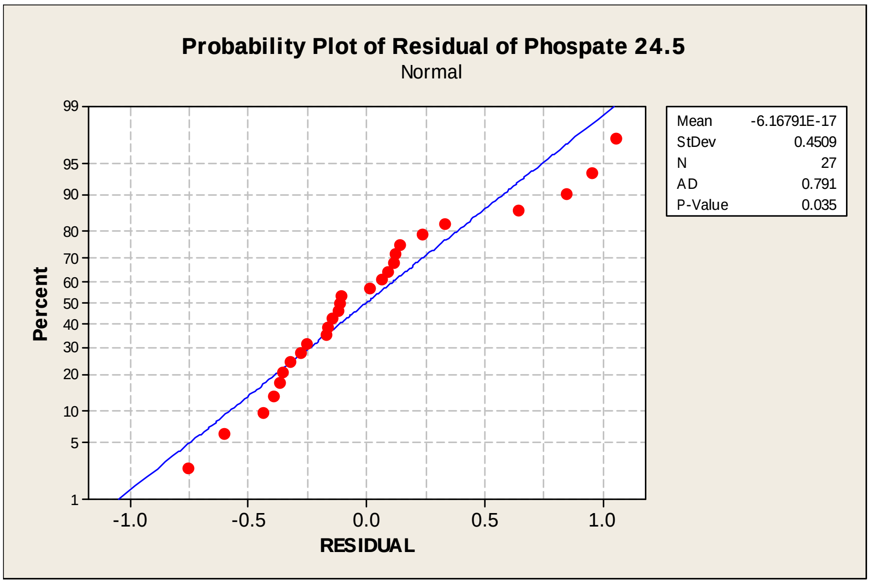
Test for Equal Variances: Phosphate_24.5 versus Distance_24.5

95% Bonferroni confidence intervals for standard deviations

Distance_24.5	N	Lower	StDev	Upper
1	13	0.405614	0.605844	1.13312
2	8	0.181657	0.298917	0.73209
3	6	0.128636	0.226683	0.70819

Bartlett's Test (normal distribution)
Test statistic = 7.02, p-value = 0.030

Levene's Test (any continuous distribution)
Test statistic = 2.58, p-value = 0.097



Kruskal-Wallis Test: Phosphate_24.5 versus Distance_24.5

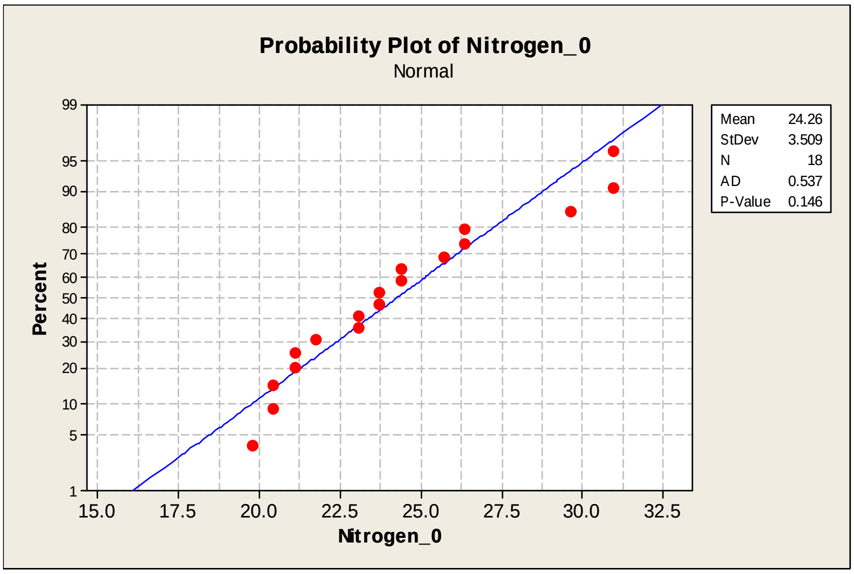
Kruskal-Wallis Test on Phosphate_24.5

Distance_24.5	N	Median	Ave Rank	Z
1	15	1.1922	16.5	1.85
2	6	1.0029	14.2	0.06
3	6	0.8640	7.5	-2.27
Overall	27		14.0	

H = 5.55   DF = 2   P = 0.062

2. Muriwai Beach chemical analyses

Week 0

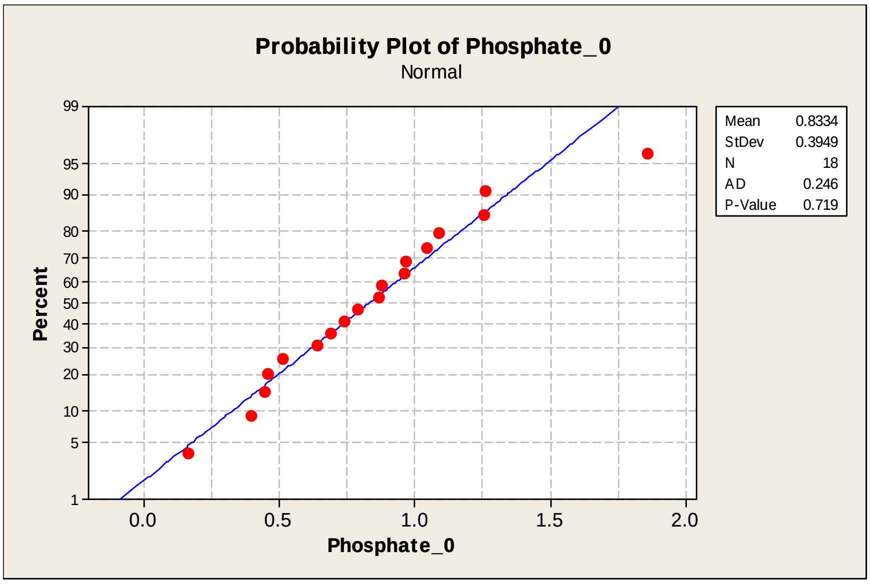


Test for Equal Variances: Nitrogen_0 versus Distance_0

```
95% Bonferroni confidence intervals for standard deviations

Distance_0  N    Lower    StDev    Upper
         1  8  2.05164  3.37598   8.2682
         2  5  1.91703  3.54721  13.6528
         3  4  2.34675  4.64216  25.2477
         4  1        *        *        *

Bartlett's Test (normal distribution)
Test statistic = 0.44, p-value = 0.804


Levene's Test (any continuous distribution)
Test statistic = 0.09, p-value = 0.911
```

One-way ANOVA: Nitrogen_0 versus Distance_0

```
Source      DF     SS    MS     F      P
Distance_0   3   14.6   4.9  0.35  0.790
Error       14  194.8  13.9
Total       17  209.3

S = 3.730   R-Sq = 6.97%   R-Sq(adj) = 0.00%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  -------+---------+---------+---------+--
1      8  24.784  3.376                       (------*------)
2      5  23.713  3.547                  (--------*--------)
3      4  24.701  4.642                    (---------*---------)
4      1  21.078      *  (-------------------*-------------------)
                         -------+---------+---------+---------+--
                             16.0      20.0      24.0      28.0

Pooled StDev = 3.730
```



Test for Equal Variances: Phosphate_0 versus Distance_0

95% Bonferroni confidence intervals for standard deviations

Distance_0	N	Lower	StDev	Upper
1	8	0.161432	0.265637	0.65058
2	5	0.290746	0.537986	2.07065
3	4	0.234280	0.463433	2.52052
4	1	*	*	*

Bartlett's Test (normal distribution)
Test statistic = 2.54, p-value = 0.280

Levene's Test (any continuous distribution)
Test statistic = 0.43, p-value = 0.660

One-way ANOVA: Phosphate_0 versus Distance_0

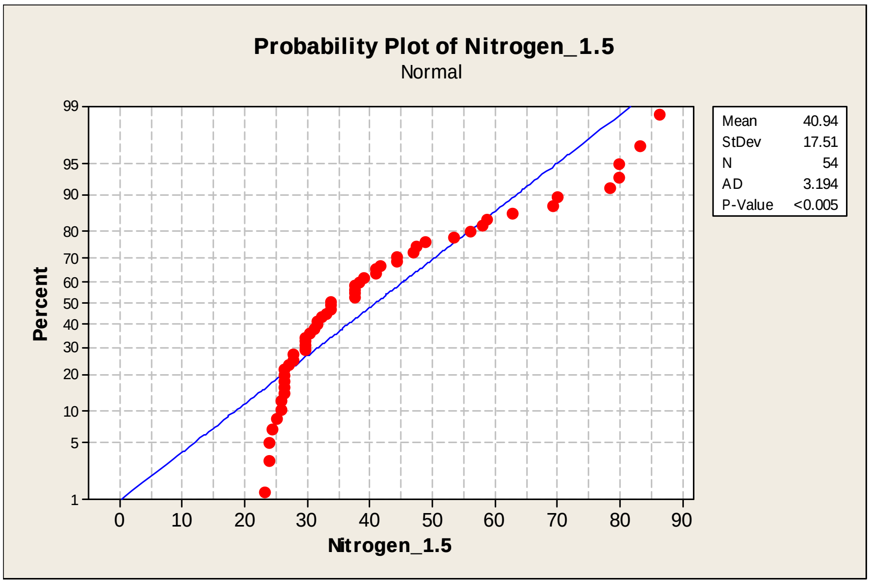
Source	DF	SS	MS	F	P
Distance_0	3	0.355	0.118	0.72	0.556
Error	14	2.296	0.164		
Total	17	2.651			

S = 0.4050   R-Sq = 13.39%   R-Sq(adj) = 0.00%

```
                                    Individual 95% CIs For Mean Based on
                                    Pooled StDev
Level   N    Mean   StDev  --------+---------+---------+---------+-
1       8  0.8421  0.2656           (-----*-----)
2       5  0.9842  0.5380            (-------*------)
3       4  0.5962  0.4634   (--------*--------)
4       1  0.9587       *  (----------------*----------------)
                           --------+---------+---------+---------+-
                                0.50      1.00      1.50      2.00
```

Pooled StDev = 0.4050

Week 1.5



Test for Equal Variances: Nitrogen_1.5 versus Distance_1.5

95% Bonferroni confidence intervals for standard deviations

Distance_1.5	N	Lower	StDev	Upper
1	20	14.8783	20.9921	34.38
2	22	8.3438	11.6041	18.46
3	10	4.7651	7.6136	16.84
4	2	4.9398	13.5074	1724.35

Bartlett's Test (normal distribution)
Test statistic = 11.70, p-value = 0.008

Levene's Test (any continuous distribution)
Test statistic = 6.38, p-value = 0.001

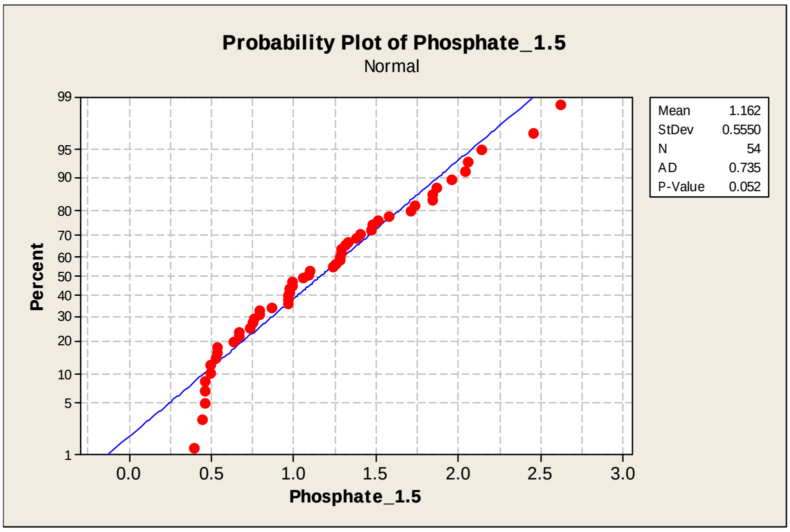
Kruskal-Wallis Test: Nitrogen_1.5 versus Distance_1.5

Kruskal-Wallis Test on Nitrogen_1.5

Distance_1.5	N	Median	Ave Rank	Z
1	20	47.43	36.8	3.32
2	22	32.61	24.3	-1.23
3	10	28.32	17.1	-2.32
4	2	34.58	21.8	-0.53
Overall	54		27.5	

H = 12.49 DF = 3 P = 0.006
H = 12.51 DF = 3 P = 0.006 (adjusted for ties)

* NOTE * One or more small samples



Test for Equal Variances: Phosphate_1.5 versus Distance_1.5

95% Bonferroni confidence intervals for standard deviations

Distance_1.5	N	Lower	StDev	Upper
1	20	0.317360	0.447769	0.7333
2	22	0.215379	0.299538	0.4765
3	10	0.239334	0.382404	0.8457
4	2	0.132086	0.361172	46.1074

Bartlett's Test (normal distribution)
Test statistic = 2.82, p-value = 0.421

Levene's Test (any continuous distribution)
Test statistic = 0.85, p-value = 0.475

General Linear Model: Phosphate_1.5 versus Distance_1.5

Factor	Type	Levels	Values
Distance_1.5	fixed	4	1, 2, 3, 4

Analysis of Variance for Phosphate_1.5, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Distance_1.5	3	9.1848	9.1848	3.0616	21.44	0.000
Error	50	7.1402	7.1402	0.1428		
Total	53	16.3250				

S = 0.377893   R-Sq = 56.26%   R-Sq(adj) = 53.64%

Unusual Observations for Phosphate_1.5

Obs	Phosphate_1.5	Fit	SE Fit	Residual	St Resid	
1	2.62080	1.69764	0.08450	0.92316	2.51	R
9	2.45535	1.69764	0.08450	0.75771	2.06	R
53	0.97160	0.71621	0.26721	0.25539	0.96	X
54	0.46083	0.71621	0.26721	-0.25539	-0.96	X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large influence.

```
Tukey 95.0% Simultaneous Confidence Intervals
Response Variable Phosphate_1.5
All Pairwise Comparisons among Levels of Distance_1.5
Distance_1.5 = 1  subtracted from:

Distance_1.5   Lower   Center    Upper  -----+---------+---------+---------
+-
2             -1.125  -0.8149  -0.5045          (---*----)
3             -1.290  -0.9008  -0.5117        (----*-----)
4             -1.727  -0.9814  -0.2363  (----------*----------)
                                        -----+---------+---------+---------
+-
                                          -1.40     -0.70      0.00
0.70


Distance_1.5 = 2  subtracted from:

Distance_1.5    Lower   Center   Upper  -----+---------+---------+---------
+-
3             -0.4690  -0.0859  0.2973                    (-----*----)
4             -0.9085  -0.1665  0.5755              (----------*---------)
                                        -----+---------+---------+---------
+-
                                          -1.40     -0.70      0.00
0.70


Distance_1.5 = 3  subtracted from:

Distance_1.5  Lower   Center   Upper  -----+---------+---------+---------+-
4            -0.8589  -0.08065 0.6976               (----------*----------)
                                      -----+---------+---------+---------+-
                                          -1.40     -0.70      0.00    0.70
```

Tukey Simultaneous Tests
Response Variable Phosphate_1.5
All Pairwise Comparisons among Levels of Distance_1.5
Distance_1.5 = 1 subtracted from:

Distance_1.5	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
2	-0.8149	0.1168	-6.980	0.0000
3	-0.9008	0.1464	-6.155	0.0000
4	-0.9814	0.2803	-3.502	0.0053

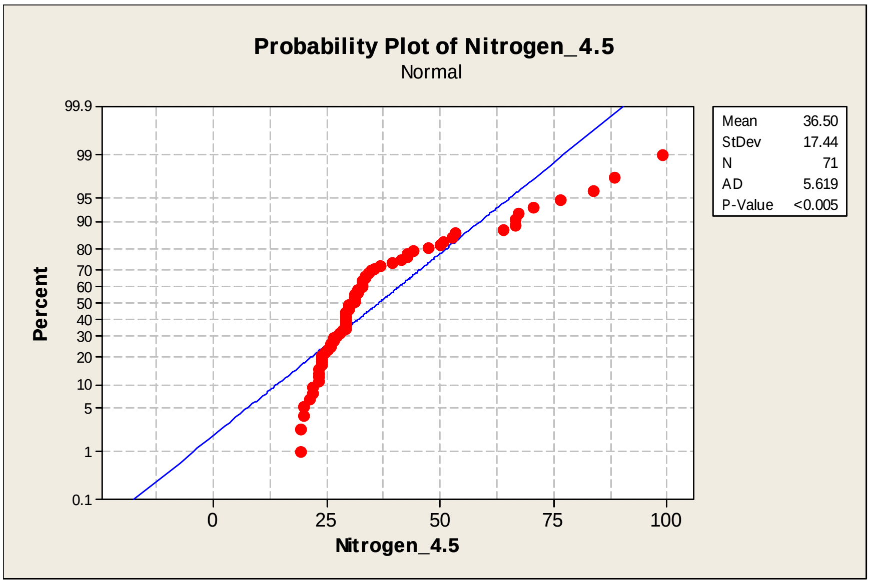
Distance_1.5 = 2 subtracted from:

Distance_1.5	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
3	-0.0859	0.1441	-0.5957	0.9329
4	-0.1665	0.2791	-0.5966	0.9326

Distance_1.5 = 3 subtracted from:

Distance_1.5	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
4	-0.08065	0.2927	-0.2755	0.9926

Week 4.5



Test for Equal Variances: Nitrogen_4.5 versus Distance_4.5

95% Bonferroni confidence intervals for standard deviations

Distance_4.5	N	Lower	StDev	Upper
1	32	15.7273	20.7788	30.047
2	21	3.3079	4.6326	7.473
3	15	10.4937	15.5209	28.164
4	3	7.3409	16.5376	208.859

Bartlett's Test (normal distribution)
Test statistic = 33.92, p-value = 0.000

Levene's Test (any continuous distribution)
Test statistic = 3.72, p-value = 0.015

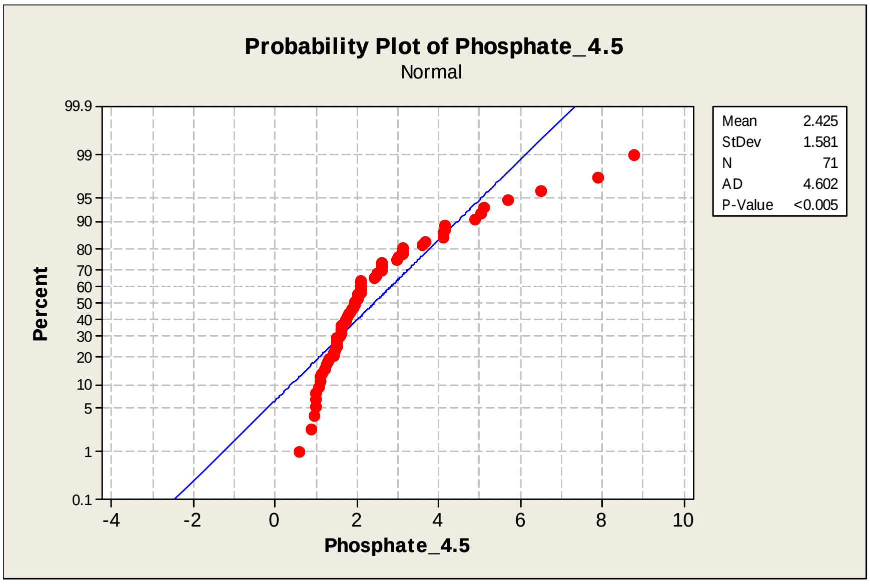
Kruskal-Wallis Test: Nitrogen_4.5 versus Distance_4.5

Kruskal-Wallis Test on Nitrogen_4.5

Distance_4.5	N	Median	Ave Rank	Z
1	32	36.23	44.9	3.29
2	21	28.98	27.1	-2.35
3	15	27.67	29.2	-1.44
4	3	33.59	37.3	0.11
Overall	71		36.0	

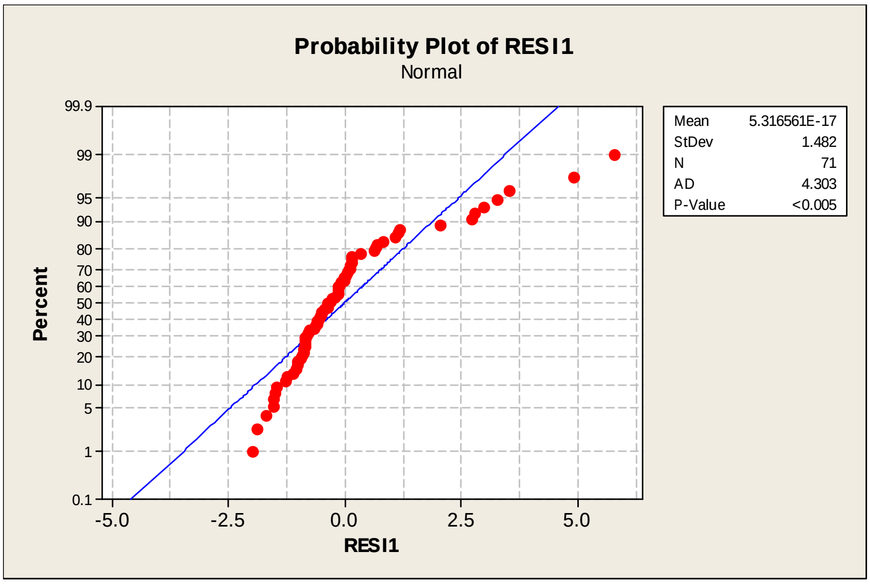
H = 11.50 DF = 3 P = 0.009
H = 11.53 DF = 3 P = 0.009 (adjusted for ties)

* NOTE * One or more small samples



Test for Equal Variances: Phosphate_4.5 versus Distance_4.5

```
95% Bonferroni confidence intervals for standard deviations

Distance_4.5   N     Lower     StDev     Upper
           1  32   1.41699   1.87211    2.7071
           2  21   0.62407   0.87399    1.4098
           3  15   0.95723   1.41580    2.5690
           4   3   0.41944   0.94492   11.9336


Bartlett's Test (normal distribution)
Test statistic = 11.82, p-value = 0.008


Levene's Test (any continuous distribution)
Test statistic = 1.63, p-value = 0.190
```



Kruskal-Wallis Test: Phosphate_4.5 versus Distance_4.5

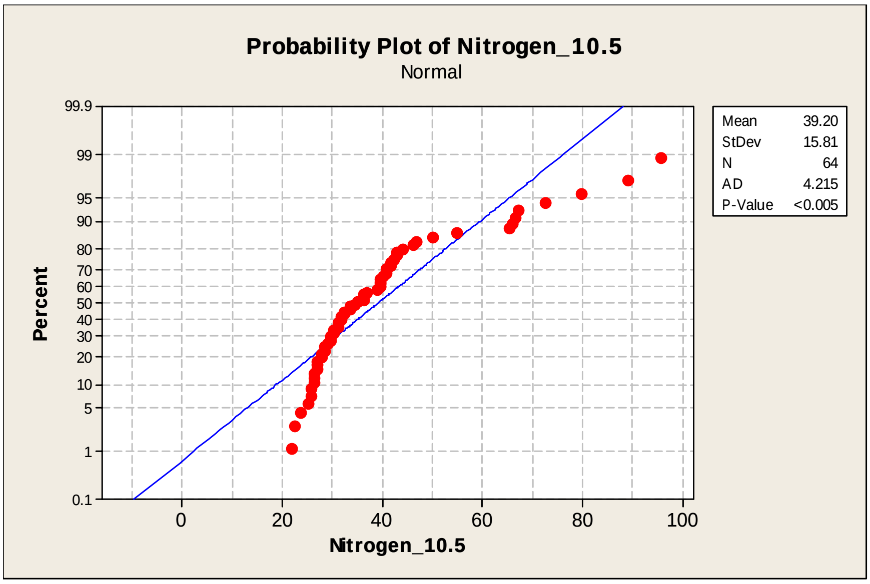
Kruskal-Wallis Test on Phosphate_4.5

Distance_4.5	N	Median	Ave Rank	Z
1	32	2.344	44.2	3.03
2	21	1.599	25.9	-2.68
3	15	1.599	29.3	-1.41
4	3	2.491	53.0	1.46
Overall	71		36.0	

H = 13.71 DF = 3 P = 0.003
H = 13.71 DF = 3 P = 0.003 (adjusted for ties)

* NOTE * One or more small samples

Week 10.5



Test for Equal Variances: Nitrogen_10.5 versus Distance_10.5

95% Bonferroni confidence intervals for standard deviations

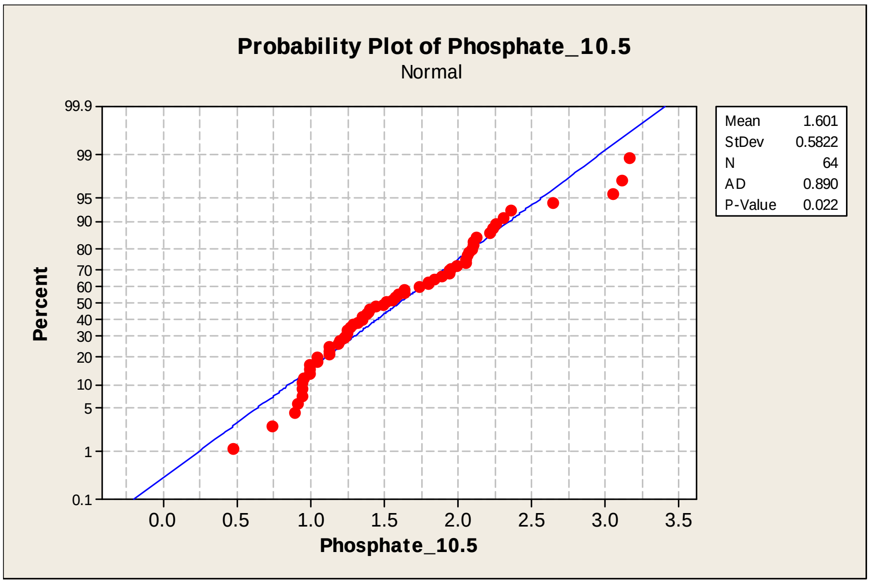
Distance_10.5	N	Lower	StDev	Upper
1	26	13.6940	18.5955	28.2567
2	19	3.4445	4.8990	8.1567
3	13	2.6528	4.0258	7.7675
4	6	2.1143	3.8077	12.6532

Bartlett's Test (normal distribution)
Test statistic = 50.70, p-value = 0.000

Levene's Test (any continuous distribution)
Test statistic = 6.07, p-value = 0.001

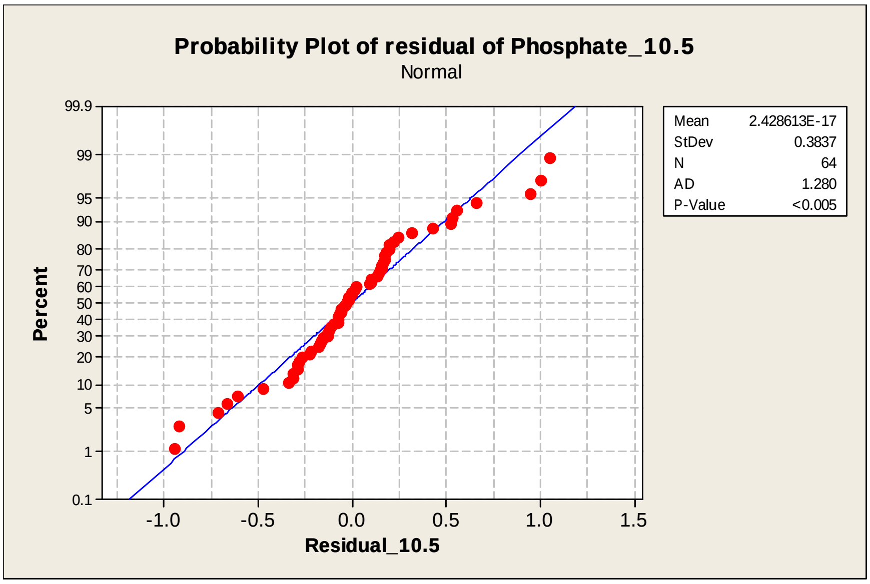
Kruskal-Wallis Test: Nitrogen_10.5 versus Distance_10.5

```
Kruskal-Wallis Test on Nitrogen_10.5

Distance_10.5    N  Median  Ave Rank      Z
1               26   43.44      47.3   5.28
2               19   34.23      29.6  -0.80
3               13   28.30      15.5  -3.70
4                6   27.97      14.2  -2.53
Overall         64              32.5

H = 33.69  DF = 3  P = 0.000
H = 33.72  DF = 3  P = 0.000  (adjusted for ties)
```



Test for Equal Variances: Phosphate_10.5 versus Distance_10.5

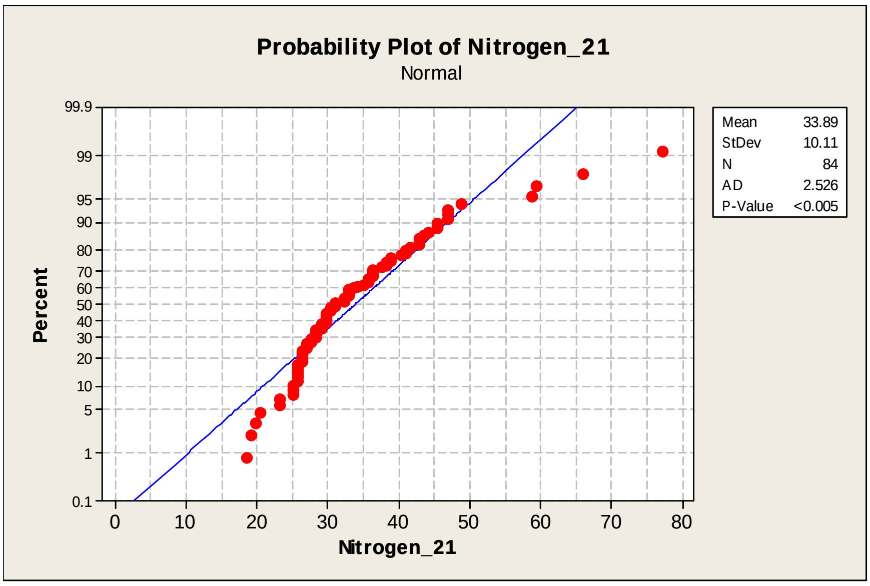
```
95% Bonferroni confidence intervals for standard deviations

Distance_10.5    N     Lower     StDev     Upper
            1   26  0.358686  0.487070  0.740124
            2   19  0.264896  0.376745  0.627274
            3   13  0.146350  0.222099  0.428524
            4    6  0.110690  0.199349  0.662444


Bartlett's Test (normal distribution)
Test statistic = 10.90, p-value = 0.012


Levene's Test (any continuous distribution)
Test statistic = 1.72, p-value = 0.173
```



Kruskal-Wallis Test: Phosphate_10.5 versus Distance_10.5

```
Kruskal-Wallis Test on Phosphate_10.5

Distance_10.5    N  Median  Ave Rank      Z
1               26  2.0769      48.9   5.84
2               19  1.3942      28.0  -1.26
3               13  0.9947      13.0  -4.23
4                6  1.2315      17.8  -2.03
Overall         64              32.5

H = 39.32  DF = 3  P = 0.000
```

Week 21



Test for Equal Variances: Nitrogen_21 versus Distance_21

95% Bonferroni confidence intervals for standard deviations

Distance_21	N	Lower	StDev	Upper
1	31	7.75383	10.2858	14.9795
2	24	2.71950	3.7346	5.7968
3	19	2.48553	3.5350	5.8858
4	10	2.70720	4.3255	9.5660

Bartlett's Test (normal distribution)
Test statistic = 37.45, p-value = 0.000

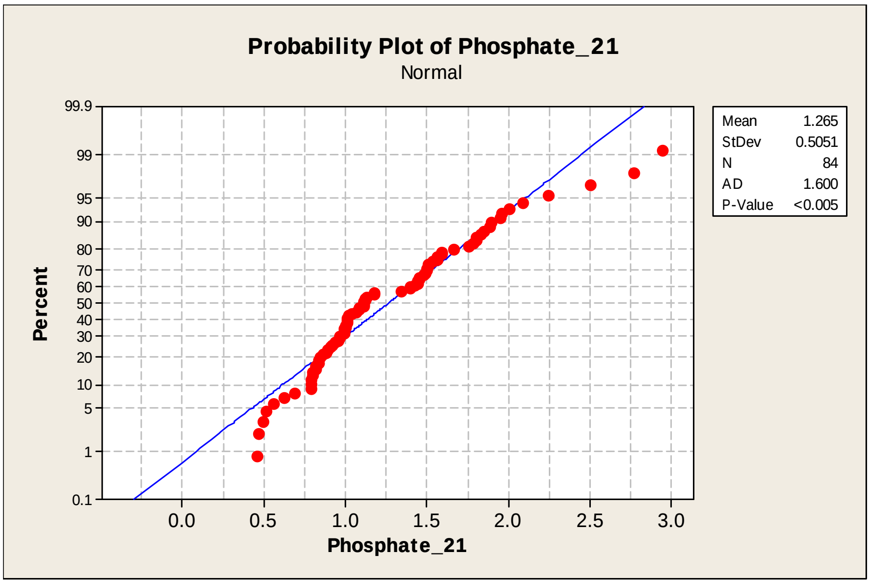
Levene's Test (any continuous distribution)
Test statistic = 4.04, p-value = 0.010

Kruskal-Wallis Test: Nitrogen_21 versus Distance_21

Kruskal-Wallis Test on Nitrogen_21

Distance_21	N	Median	Ave Rank	Z
1	31	41.50	66.7	6.95
2	24	29.64	37.9	-1.09
3	19	26.35	22.6	-4.04
4	10	25.69	16.4	-3.61
Overall	84		42.5	

H = 55.43 DF = 3 P = 0.000
H = 55.52 DF = 3 P = 0.000 (adjusted for ties)



Test for Equal Variances: Phosphate_21 versus Distance_21

95% Bonferroni confidence intervals for standard deviations

Distance_21	N	Lower	StDev	Upper
1	31	0.303944	0.403195	0.587187
2	24	0.177419	0.243643	0.378180
3	19	0.136402	0.193997	0.323002
4	10	0.114739	0.183328	0.405434

Bartlett's Test (normal distribution)
Test statistic = 16.22, p-value = 0.001

Levene's Test (any continuous distribution)
Test statistic = 2.81, p-value = 0.045

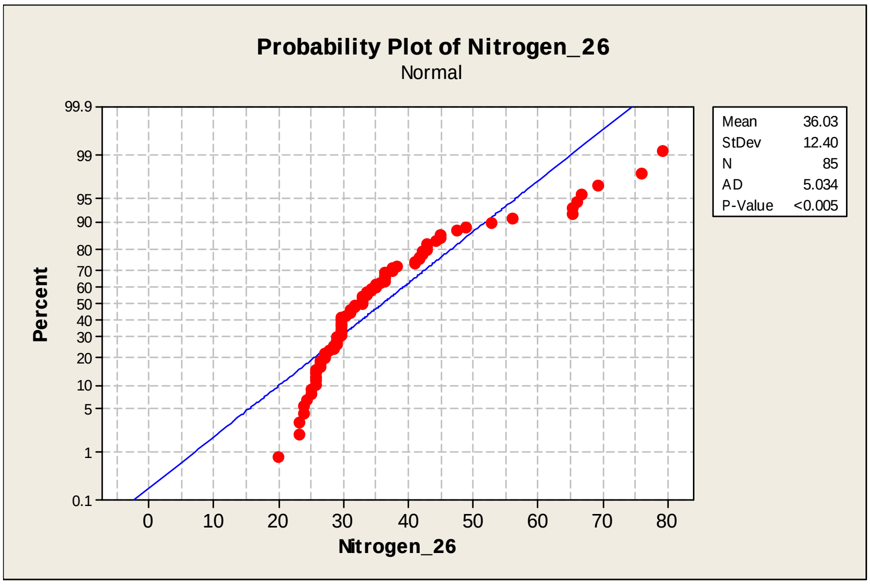
Kruskal-Wallis Test: Phosphate_21 versus Distance_21

Kruskal-Wallis Test on Phosphate_21

Distance_21	N	Median	Ave Rank	Z
1	31	1.6594	67.5	7.20
2	24	1.0946	39.6	-0.69
3	19	0.8588	19.7	-4.63
4	10	0.8066	15.2	-3.77
Overall	84		42.5	

H = 62.18 DF = 3 P = 0.000
H = 62.18 DF = 3 P = 0.000 (adjusted for ties)

Week 26



Test for Equal Variances: Nitrogen_26 versus Distance_26

95% Bonferroni confidence intervals for standard deviations

Distance_26	N	Lower	StDev	Upper
1	27	10.5395	14.2381	21.4291
2	26	3.8335	5.2056	7.9102
3	18	2.7550	3.9522	6.7012
4	14	3.8527	5.7683	10.7707

Bartlett's Test (normal distribution)
Test statistic = 43.15, p-value = 0.000

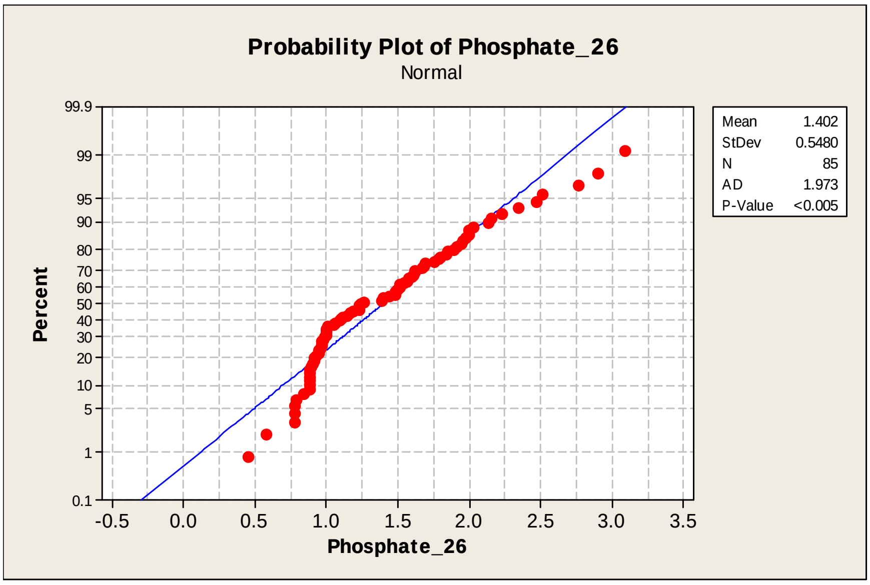
Levene's Test (any continuous distribution)
Test statistic = 6.58, p-value = 0.000

Kruskal-Wallis Test: Nitrogen_26 versus Distance_26

Kruskal-Wallis Test on Nitrogen_26

Distance_26	N	Median	Ave Rank	Z
1	27	42.82	67.5	6.24
2	26	31.62	41.8	-0.29
3	18	28.98	25.6	-3.36
4	14	26.35	20.2	-3.78
Overall	85		43.0	

H = 47.50 DF = 3 P = 0.000
H = 47.62 DF = 3 P = 0.000 (adjusted for ties)



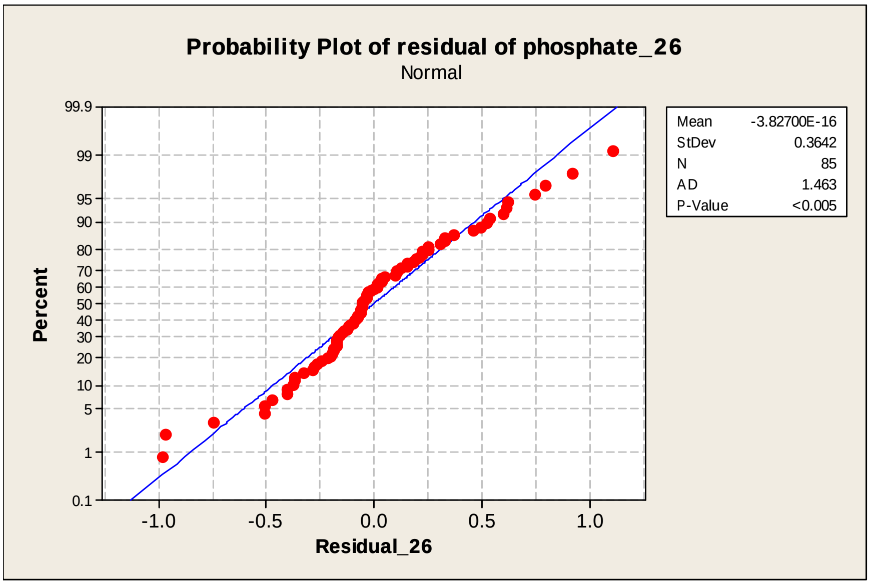
Test for Equal Variances: Phosphate_26 versus Distance_26

95% Bonferroni confidence intervals for standard deviations

Distance_26	N	Lower	StDev	Upper
1	27	0.374201	0.505520	0.760830
2	26	0.191242	0.259693	0.394614
3	18	0.221315	0.317487	0.538318
4	14	0.194151	0.290686	0.542774

Bartlett's Test (normal distribution)
Test statistic = 13.05, p-value = 0.005

Levene's Test (any continuous distribution)
Test statistic = 2.36, p-value = 0.077



Kruskal-Wallis Test: Phosphate_26 versus Distance_26

Kruskal-Wallis Test on Phosphate_26

Distance_26	N	Median	Ave Rank	Z
1	27	1.9483	67.9	6.35
2	26	1.2438	41.3	-0.42
3	18	0.9483	24.7	-3.54
4	14	0.9352	21.6	-3.55
Overall	85		43.0	

H = 48.08 DF = 3 P = 0.000
H = 48.08 DF = 3 P = 0.000 (adjusted for ties)

3. Diversity analysis (ANOSIM tests)

3.1 Analysis of Similarities of sampling site at distance 3

One-Way Analysis

Factor Values

Factor: TransectDistance

13
23
33
43

Global Test

Sample statistic (Global R): 0.186
Significance level of sample statistic: 1.6%
Number of permutations: 999 (Random sample from 488864376)
Number of permuted statistics greater than or equal to Global R: 15

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
13, 23	0.461	0.8	126	126	1
13, 33	0.046	36.5	126	126	46
13, 43	0.05	33.3	126	126	42
23, 33	0.339	2.4	126	126	3
23, 43	0.35	0.8	126	126	1
33, 43	0.037	27	126	126	34

3.2 Analysis of Similarities of sampling sites at distance 4

One-Way Analysis

Factor Values

Factor: TransectDistance

14
24
34
44

Global Test

Sample statistic (Global R): 0.428
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 488864376)
Number of permuted statistics greater than or equal to Global R: 0

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
14, 24	0.194	5.6	126	126	7
14, 34	0.75	0.8	126	126	1
14, 44	0.05	34.9	126	126	44
24, 34	0.52	0.8	126	126	1
24, 44	0.318	2.4	126	126	3
34, 44	0.632	0.8	126	126	1

3.3 Analysis of Similarities

One-Way Analysis

Factor Values

Factor: TransectDistance
15
25
35
45

Global Test

Sample statistic (Global R): 0.026
Significance level of sample statistic: 35.1%
Number of permutations: 999 (Random sample from a large number)
Number of permuted statistics greater than or equal to Global R: 350

Pairwise Tests

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
15, 25	0.038	37.3	126	126	47
15, 35	-0.05	54.8	126	126	69
15, 45	-0.079	64.8	210	210	136
25, 35	0.138	19	126	126	24
25, 45	0.04	32.9	462	462	152
35, 45	0.06	23.4	462	462	108

4. Faunal/floral inventories

Location	Rocky shore	Soft shore
Islington Bay	*Acanthochitona zelandica*	*Glycera tesselata*
	Alpheus sp.	*Heteromastus filiformis*
	Amphiporus sp.	*Lepidonotus polychroma*
	Anthopleura aureoradiata	*Macroclymenella stewartensis*
	Atrina zelandica	*Ophiodromus angustifrons*
	Austrominius modestus	*Perinereis nuntia*
	Austrovenus stutchburyi	*Prionospio* sp.
	Balanus trigonus	*Prionospio* sp. 1
	Chiton glaucus	Sabellid sp. 1
	Cominella glandiformis	Sabellidae sp.
	Cominella virgata	Spionid sp. 9
	Crassostrea gigas	Spionidae sp.
	Cyclograpsus lavauxi	Corophiidae sp.
	Desis robsoni	*Corophium acutum*
	Diloma subrostrata	*Cyclaspis argus*
	Eulalia microphylla	*Halicarcinus cookii*
	Halicarcinus pubescens	*Halicarcinus whitei*
	Helice crassa	*Helice crassa*
	Hemigrapsus crenulatus	*Hemileucon comes*
	Isactinia olivacea	*Pagurapseudes* sp.
	Isocladus inaccuratus	*Pagurus novaezelandiae*
	Lepidonotus polychroma	*Paraphoxus* sp. 1
	Lepsiella scobina	*Paraphoxus* sp. 2
	Macomona liliana	*Anthopleura aureoradiata*
	Melagraphia aethiops	*Austrovenus stutchburyi*
	Micrelenchus tenebrosus	*Felaniella zelandica*
	Nerita atramentosa	*Nucula hartvigiana*
	Notoacmea helmsi	*Paphies australis*
	Notoacmea parviconoidea	*Theora lubrica*
	Nucula hartvigiana	*Cominella adspersa*
	Onchidella nigricans	*Cominella glandiformis*
	Pagurus novizealandiae	*Diloma subrostrata*
	Paphies australis	*Micrelenchus tenebrosus*
	Petrolisthes elongatus	*Notoacmaea helmsi*
	Pilumnopeus serratifrons	*Turbo smaragdus*
	Pilumnus lumpinus	*Zeacumantus lutulentus*
	Platyhelminthes sp.	*Amaurochiton glaucus*
	Plaxiphora caelata	Polyplacophora sp.
	Pomatoceros caeruleus	Ostracoda sp. 1
	Saccostrea glomerata	*Austrominius modestus*
	Seila cincta	
	Siphonaria australis	
	Sphaeroma quoyanum	
	Styela clava	
	Styela plicata	
	Sypharochiton pelliserpentis	
	Talorchestia quoyana	
	Turbo smaragdus	
	Watersipora sp.	
	Xenostrobus pulex	
	Zeacumantus lutulentus	

Location	Rocky shore	Soft shore
Emu Point	*Aaptos aaptos*	
	Acanthochitona zelandica	
	Acanthoclinus fuscus	
	Acanthoclinus littoreus	
	Acarina sp.	
	Alpheus sp.	
	Amphipoda sp.	
	Amphiporus sp.	
	Anthopleura aureoradiata	
	Asterocarpa cerea	
	Asterocarpa coerulea	
	Austrolittorina antipodum	
	Austrominius modestus	
	Austrovenus stutchburyi	
	Balanus trigonus	
	Barnea similis	
	Beania sp.	
	Branchiomma sp.	
	Buccinulum lineum	
	Buccinulum vittatum	
	Calantica spinosa	
	Carpophyllum maschalocarpum	
	Cellana ornata	
	Cellana radians	
	Chamaesipho columna	
	Chiton glaucus	
	Cirratulidae sp.	
	Cliona celata	
	Cnemidocarpa bicornuta	
	Codium adhaerens	
	Codium fragilis	
	Colpomenia sinuosa	
	Cominella glandiformis	
	Cominella maculosa	
	Cominella virgata	
	Cookia sulcata	
	Corallina officinalis	
	Coscinasterias muricata	
	Crassostrea gigas	
	Cryptoconchus porosus	
	Cyclograpsus lavauxi	
	Cystophora retroflexa	
	Desis robsoni	
	Diloma bicanaliculata	
	Diloma subrostrata	
	Diloma zelandica	
	Dynamenella insulsa	
	Ecklonia radiata	
	Epopella plicata	
	Eulalia microphylla	
	Evechinus chloroticus	
	Exosphaeroma gigas	

Location	Rocky shore	Soft shore
Emu Point (cont.)	*Flabelligera affinis*	
	Fossarina rimata	
	Halicarcinus pubescens	
	Haliplanellidae sp.	
	Haustrum haustorium	
	Hemigrapsus edwardsi	
	Herpetopoma bella	
	Heterozius rotundifrons	
	Hildenbrandtia sp.	
	Hormosira banksii	
	Hydroides norvegicus	
	Iais sp.	
	Ircinia sp.	
	Irus reflexus	
	Isactinia olivacea	
	Ischnochiton maorianus	
	Isocladus armatus	
	Isocladus dulciculus	
	Jania sp.	
	Leathesia difformis	
	Lepidonotus polychroma	
	Lepsiella scobina	
	Leptochiton inquinatus	
	Leuconopsis obsoleta	
	Ligia novaezelandiae	
	Maoricolpus roseus	
	Maoricrypta costata	
	Maoricrypta monoxyla	
	Melagraphia aethiops	
	Micrelenchus tenebrosus	
	Microciona sp.	
	Microcosmus kura	
	Modiolarca impacta	
	Mytilus edulis	
	Neosabellaria kaiparaensis	
	Nerita atramentosa	
	Notoacmea helmsi	
	Notoacmea parviconoidea	
	Notoplax violacea	
	Nucula hartvigiana	
	Onchidella nigricans	
	Ostracoda sp.	
	Pagurus novizealandiae	
	Patiriella regularis	
	Paxula paxillus	
	Perinereis novaehollandiae	
	Perna canaliculus	
	Petrolisthes elongatus	
	Pilumnopeus serratifrons	
	Pisinna zosterophila	
	Platynereis australis	
	Polymastia sp.	
	Pomatoceros caeruleus	

Location	Rocky shore	Soft shore
Emu Point (cont.)	*Pyura rugata*	
	Risellopsis varia	
	Rissoina chathamensis	
	Saccostrea glomerata	
	Sigapatella novaezelandiae	
	Siphonaria australis	
	Sphaeromatidae sp.	
	Splachnidium rugosum	
	Stegnaster inflatus	
	Stephopoma roseum	
	Styela clava	
	Sypharochiton pelliserpentis	
	Sypharochiton sinclairii	
	Talorchestia sp.	
	Taron dubius	
	Tethya aurantium	
	Tetraclitella depressa	
	Thais orbita	
	Trachelochismus melobesia	
	Trochus viridis	
	Turbo smaragdus	
	Watersipora sp.	
	Xenostrobus pulex	
	Xenostrobus securis	
	Zelithophaga truncata	
Near Otahuhu Point		*Talorchestia quoyana*
		Exosphaeroma gigas
		Oligochaeta sp.
		Sphaerosyllis
Home Bay	*Aaptos aaptos*	Oligochaeta sp.
	Acanthochitona zelandica	Nereidae sp.
	Acanthoclinus fuscus	*Sphaerosyllis* sp.
	Acarina sp.	*Anoteropsis hilaris*
	Actinia tenebrosa	*Cirolana arcuata*
	Allostichaster polyplax	Amphipoda indet
	Alope spinifrons	*Cyclograpsus lavauxi*
	Alpheus sp.	*Exosphaeroma gigas*
	Amaurobioides maritima	*Hemigrapsus crenulatus*
	Amphiporus sp.	*Isocladus armatus*
	Anisolabis littorea	*Talorchestia quoyana*
	Arthritica bifurca	*Fellaster zelandiae*
	Ascidiacea sp.	*Xenostrobus pulex*
	Asterocarpa cerea	*Leispella scobina*
	Asterocarpa coerulea	*Turbo smaragdus*
	Austrolittorina antipodum	*Melagraphia aethiops*
	Austrominius modestus	*Notoacmaea helmsi*
	Austromitra rubiginosa	
	Balanus trigonus	
	Balanus vestitus	
	Beania sp.	
	Betaeus aequimanus	

Location	Rocky shore	Soft shore
Home Bay (cont.)	*Borniola reniformis*	
	Branchiomma sp.	
	Bryopsis plumosa	
	Buccinulum lineum	
	Buccinulum mariae	
	Buccinulum pallidum powelli	
	Buccinulum vittatum	
	Calantica spinosa	
	Carpophyllum maschalocarpum	
	Cellana ornata	
	Cellana radians	
	Chaetopterus sp.	
	Chamaesipho brunnea	
	Chamaesipho columna	
	Chiton glaucus	
	Chlamys zelandiae	
	Cliona celata	
	Cnemidocarpa bicornuta	
	Codium adhaerens	
	Colpomenia peregrina	
	Colpomenia sinuosa	
	Cominella maculosa	
	Cominella virgata	
	Corallina officinalis	
	Coscinasterias muricata	
	Crassostrea gigas	
	Cryptoconchus porosus	
	Culicia rubeola	
	Cyclograpsus lavauxi	
	Cystophora retroflexa	
	Cystophora torulosa	
	Dendrostomum aeneum	
	Desis robsoni	
	Diadumene lineata	
	Didemnum candidum	
	Diloma bicanaliculata	
	Diloma zelandica	
	Dodecaceria berkeleyi	
	Ecklonia radiata	
	Elamena producta	
	Elysia maoria	
	Epopella plicata	
	Eudoxochiton nobilis	
	Eulalia microphylla	
	Evechinus chloroticus	
	Exosphaeroma gigas	
	Filograna sp.	
	Flabelligera affinis	
	Galeolaria hystrix	
	Gobiesocidae sp.	
	Gregariella barbata	
	Halicarcinus cookii	

Location	Rocky shore	Soft shore
Home Bay (cont.)	*Halicarcinus pubescens*	
	Halichondria sp.	
	Haustrum haustorium	
	Hemigrapsus edwardsi	
	Herpetopoma bella	
	Heterozius rotundifrons	
	Hiatella arctica	
	Hildenbrandtia sp.	
	Hormosira banksii	
	Hydroides norvegicus	
	Isactinia olivacea	
	Ischnochiton maorianus	
	Isocladus dulciculus	
	Isocradactis magna	
	Isoparactis ferax	
	Leathesia difformis	
	Lepidonotus polychroma	
	Lepidonotus purpureus	
	Lepsiella scobina	
	Leptochiton inquinatus	
	Leuconopsis obsoleta	
	Lichina confinis	
	Ligia novaezelandiae	
	Lithophyllum sp.	
	Maoricolpus roseus	
	Maoricrypta costata	
	Maoricrypta monoxyla	
	Marginella cairoma	
	Marphysa depressa	
	Melagraphia aethiops	
	Merelina taupoensis	
	Mesoginella koma	
	Microciona sp.	
	Microcosmus kura	
	Modiolarca impacta	
	Monia zelandica	
	Mytilus edulis	
	Nemertea sp.	
	Neosabellaria kaiparaensis	
	Nerita atramentosa	
	Notoacmea daedala	
	Notoacmea parviconoidea	
	Notoplax violacea	
	Ocnus brevidentis	
	Octocorallia sp.	
	Okamia thilenii	
	Onchidella nigricans	
	Onithochiton neglectus	
	Ophionereis fasciata	
	Pagurus novizealandiae	
	Palaemon affinis	
	Patiriella regularis	
	Paxula paxillus	

Location	Rocky shore	Soft shore
Home Bay (cont.)	*Perinereis novaehollandiae*	
	Perinereis nuntia	
	Perinereis sp.	
	Perna canaliculus	
	Petrocheles spinosus	
	Petrolisthes elongatus	
	Pherusa parmatus	
	Philobrya sp.	
	Pilumnus lumpinus	
	Pilumnus novaezelandiae	
	Pisidium hodgkini	
	Pisinna zosterophila	
	Plagusia chabrus	
	Platyhelminthes sp.	
	Platynereis australis	
	Pomatoceros caeruleus	
	Pseudechinus huttoni	
	Pyura rugata	
	Rhyssoplax aerea	
	Risellopsis varia	
	Rissoina chathamensis	
	Saccostrea glomerata	
	Scolioplanes sp.	
	Scutus breviculus	
	Serpulorbis sp.	
	Sigapatella novaezelandiae	
	Siphonaria australis	
	Sphaerium novaezelandiae	
	Sphaeromatidae sp.	
	Spirorbinae sp.	
	Splachnidium rugosum	
	Steginoporella perplexa	
	Stegnaster inflatus	
	Stephopoma roseum	
	Suterilla imperforata	
	Syngnathidae sp.	
	Sypharochiton pelliserpentis	
	Sypharochiton sinclairii	
	Talorchestia sp.	
	Taron dubius	
	Terebellidae sp.	
	Tethya aurantium	
	Tetraclitella depressa	
	Thais orbita	
	Thoristella oppressa	
	Timarete anchylochaetus	
	Trachelochismus melobesia	
	Trochus viridis	
	Tugali suteri	
	Turbo smaragdus	
	Watersipora sp.	
	Xenostrobus securis	
	Zeacumantus subcarinatus	

Location	Rocky shore	Soft shore
Mullet Bay		*Chamaesipho columna* *Paguris novaezelandiae* *Anisolabis littorea* *Isocladus armatus* *Fellaster zelandiae* *Crepidula monoxyla* *Nerita atramentosa* Platyhelminthes sp.
Station Bay		*Watersipora cucullata* Nemertean sp. *Forsterygion* spp. *Chaetopterus* sp. *Flabelligera affinis* Hesionidae sp. *Lepidonotus polychroma* *Ophiodromus angustifrons* *Pectinaria australis* *Perinereis novaehollandiae* *Perinereis nuntia* *Pomatoceros caeruleus* *Protolaeospira* sp. *Sabellaria kaiparaensis* *Spirorbis borealis* *Forsterygion varium* *Corella eumyota* *Microcosmos kura* *Pyura rugata* *Styela clava* *Pagurus novizealandiae* *Halicarcinus cookii* *Halicarcinus pubescens* *Notomithrax minor* *Pilumnopeus serratifrons* *Alpheus richardsoni* *Palaemon affinis* *Austrominius modestus* *Balanus trigonis* *Alpheus novaezelandiae* *Alpheus richardsoni* Balanus amphitrite Balanus decorus *Astropecten polyacanthus* *Coscinasterias muricata* *Luidia maculata* *Patiriella regularis* *Echinocardium cordatum* *Evechinus chloroticus* *Fellaster zelandiae* Holothuroidea sp. Apodida sp.1 *Amphiura* sp. *Ophionereis fasciata*

Location	Rocky shore	Soft shore
Station Bay (cont.)		*Atrina zelandica*
		Chlamys zelandiae
		Crassostrea gigas
		Dosinia subrosea
		Dosinia zelandica
		Gari lineolata
		Macomona liliana
		Modiolarca impacta
		Myadora striata
		Paphies australis
		Perna canaliculus
		Soletellina nitida
		Venerupis largillierti
		Xenostrobus pulex
		Chlamys zelandiae
		Crassostrea gigas
		Dosina zelandica
		Modiolarca impacta
		Perna canaliculus
		Venerupis largillierti
		Xenostrobus pulex
		Atrina zelandica
		Dosinia subrosea
		Gari lineolata
		Macomona lilliana
		Myadora striata
		Paphies australis
		Soletellina nitida
		Alcithoe arabica
		Amalda australis
		Bulla quoyii
		Cominella adspersa
		Cominella maculosa
		Cominella virgata
		Crepidula monoxyla
		Diloma nigerrima
		Haustrum haustorium
		Lepsiella scobina
		Maoricrypta monoxyla
		Marginella pygmaea
		Melagraphia aethiops
		Mesoginella koma
		Microcosmos kura
		Nerita atramentosa
		Notoacmea parviconoidea
		Onchidella nigricans
		Pyura rugata
		Risellopsis varia
		Siphonaria australis
		Struthiolaria papulosa
		Struthiolaria vermis vermis
		Styela clava
		Tanea zelandica
		Turbo smaragdus

Location	Rocky shore	Soft shore
Station Bay (cont.)		*Umbonium zelandicum*
		Amaurochiton glaucus
		Chiton glaucus
		Ischnochiton maorianus
		Sypharochiton pelliserpentis
		Sypharochiton sinclairi
Waikarapupu Bay	*Acanthochitona zelandica*	*Scolioplanes sp.*
	Acanthoclinus fuscus	*Chaerodes concolor*
	Acarina sp.	*Diastylis insularum*
	Actinia tenebrosa	*Exosphaeroma gigas*
	Actinothoe albocincta	Haustoriidae sp.
	Allostichaster insignis	*Pagurus novaezelandiae*
	Alope spinifrons	*Tailochestia quoyana*
	Amphipoda sp.	*Crepidula monoxyla*
	Amphiporus sp.	*Maoricrypta monoxyla*
	Anthopleura aureoradiata	*Melagraphia aethiops*
	Apophloea sinclairii	*Turbo smaragdus*
	Arthritica bifurca	
	Ascidiacea sp.	
	Asterocarpa cerea	
	Asterocarpa coerulea	
	Austrolittorina antipodum	
	Balanus trigonus	
	Beania sp.	
	Betaeus aequimanus	
	Borniola reniformis	
	Branchiomma sp.	
	Buccinulum pallidum powelli	
	Buccinulum vittatum	
	Cantharidella tesselata	
	Carpophyllum flexuosum	
	Carpophyllum maschalocarpum	
	Carpophyllum plumosum	
	Cellana ornata	
	Cellana radians	
	Cellana stellifera	
	Chamaesipho brunnea	
	Chamaesipho columna	
	Chiton glaucus	
	Cliona celata	
	Cnemidocarpa bicornuta	
	Codium adhaerens	
	Colpomenia sinuosa	
	Cominella maculosa	
	Cominella virgata	
	Corallina officinalis	
	Coscinasterias muricata	
	Culicia rubeola	
	Cyclograpsus lavauxi	
	Cystophora retroflexa	
	Cystophora torulosa	

Location	Rocky shore	Soft shore
Waikarapupu Bay (cont.)	*Diloma bicanaliculata*	
	Diloma zelandica	
	Ecklonia radiata	
	Epopella plicata	
	Eulalia microphylla	
	Evechinus chloroticus	
	Exosphaeroma chilensis	
	Flabelligera affinis	
	Galeolaria hystrix	
	Gigartina alveata	
	Gobiesocidae sp.	
	Halicarcinus pubescens	
	Halichondria sp.	
	Haustrum haustorium	
	Herpetopoma bella	
	Heterozius rotundifrons	
	Hiatella arctica	
	Hildenbrandtia sp.	
	Hormosira banksii	
	Hydroides norvegicus	
	Isactinia olivacea	
	Ischnochiton maorianus	
	Isoparactis ferax	
	Jania sp.	
	Leathesia difformis	
	Lepidonotus polychroma	
	Lepsiella scobina	
	Leptochiton inquinatus	
	Leptograpsus variegatus	
	Leuconopsis obsoleta	
	Lichina confinis	
	Maoricrypta costata	
	Maoricrypta monoxyla	
	Marginella cairoma	
	Melagraphia aethiops	
	Mesoginella koma	
	Microciona sp.	
	Modiolarca impacta	
	Monia zelandica	
	Nemertea sp.	
	Neosabellaria kaiparaensis	
	Nereididae sp.	
	Nerita atramentosa	
	Notoacmea parviconoidea	
	Notoplax violacea	
	Ocnus brevidentis	
	Octocorallia sp.	
	Odontosyllis sp.	
	Onchidella nigricans	
	Onithochiton neglectus	
	Ophionereis fasciata	
	Ostrea sp.	
	Pagurus novizealandiae	

Location	Rocky shore	Soft shore
Waikarapupu Bay (cont.)	*Palaemon affinis*	
	Patiriella regularis	
	Paxula paxillus	
	Petrocheles spinosus	
	Petrolisthes elongatus	
	Petrolisthes novaezelandiae	
	Pherusa parmatus	
	Pilumnus lumpinus	
	Pisidium hodgkini	
	Pisinna zosterophila	
	Platyhelminthes sp.	
	Plaxiphora caelata	
	Pomatoceros caeruleus	
	Pycnogonida sp.	
	Risellopsis varia	
	Rissoa hamiltoni	
	Rissoina chathamensis	
	Saccostrea glomerata	
	Sargassum sinclairii	
	Scutus breviculus	
	Serpulorbis sp.	
	Sigapatella novaezelandiae	
	Sphaerium novaezelandiae	
	Splachnidium rugosum	
	Stegnaster inflatus	
	Stephopoma roseum	
	Stichopus mollis	
	Styela clava	
	Sypharochiton pelliserpentis	
	Sypharochiton sinclairii	
	Talorchestia quoyana	
	Talorchestia sp.	
	Taron dubius	
	Tethya aurantium	
	Tetraclitella depressa	
	Thais orbita	
	Trachelochismus pinnulatus	
	Tugali elegans	
	Tugali suteri	
	Turbo smaragdus	
	Watersipora sp.	
	Xiphophora chondrophylla	
	Zeacumantus lutulentus	
	Zeacumantus subcarinatus	