Sedimentation

its impact on estuaries

ALPHA

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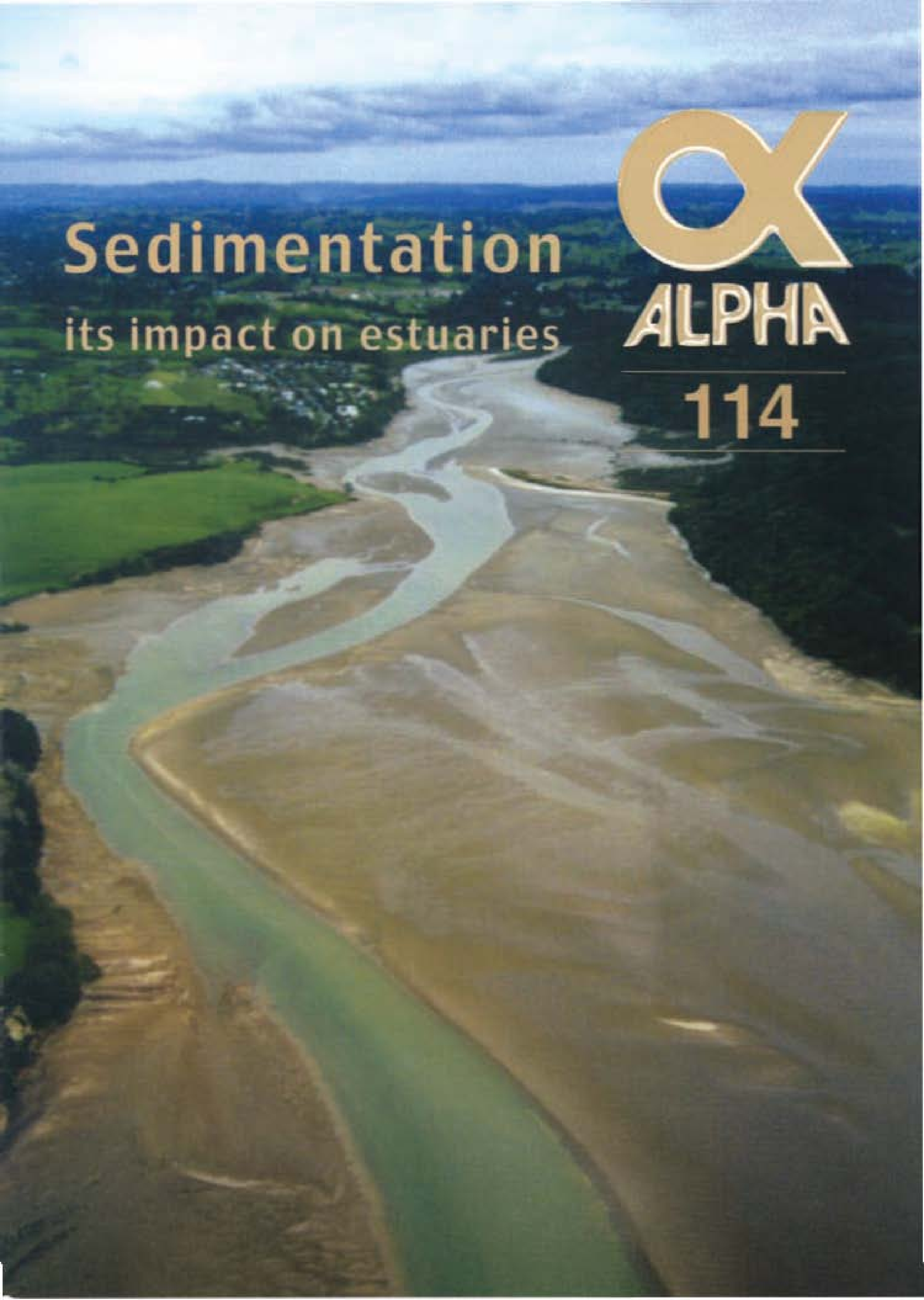
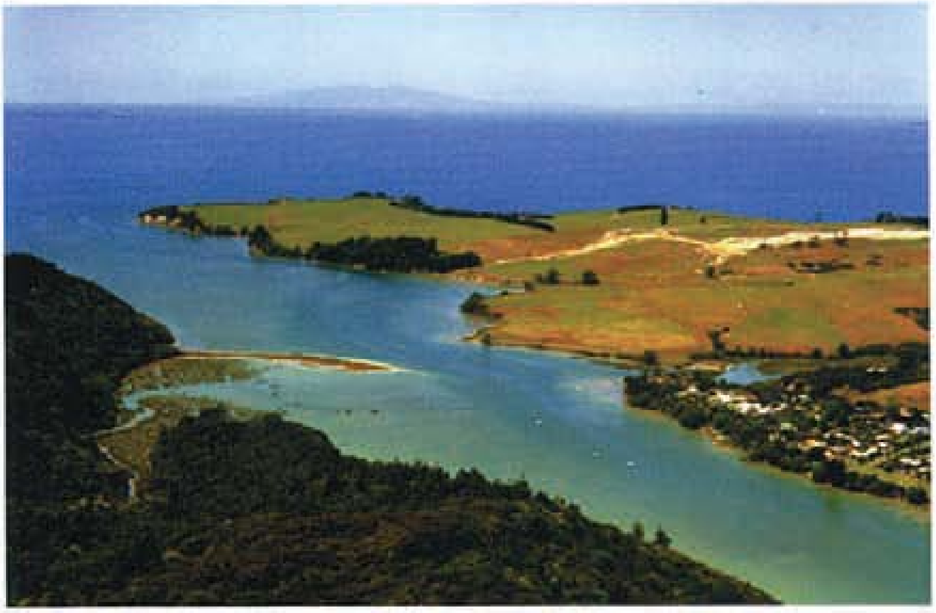




Okura estuary, situated 20 mins north of Auckland. This estuary is a dynamic and important ecosystem which forms part of the Long Bay–Okura Marine Reserve (established 1995).

Estuaries are some of the world's most diverse and productive systems. They contain a wide range of habitats, from exposed intertidal sand flats, deep estuarine channels, rocky platforms and seagrass meadows to sheltered mangrove forests and fringing marshes. This great variety of different habitats provides a wealth of living space, food and refuge for a myriad of plant and animal species, including humans. Hence we consider estuaries to be important and valuable for ecological, economic and cultural reasons. New Zealand is one of the most maritime nations in the world; we have a long shoreline and more than 300 estuaries that cover an area of 100,000 hectares. These estuaries range in type from drowned river valleys through bar-built estuaries to lagoons and fjords.

Humans prefer to inhabit coastal areas – more than half of the world's population lives within 100 km of the sea, and often the densest populations can be found beside rivers and estuaries. New Zealand is no exception: our largest settlements – Auckland, Wellington, Christchurch and Dunedin – are near the coast, and they all evolved around estuaries. Consequently, it is not surprising that estuaries worldwide, including those in New Zealand, are under increasing pressure from human development and population growth. The most significant threats to estuarine biodiversity include alteration and loss of habitat, chemical pollution and eutrophication, invasion of alien species, over-exploitation of marine resources and global climate change.

Estuaries are on the receiving end of human activities in the surrounding catchment. In New Zealand deforestation and catchment development has resulted in land erosion and accelerated infilling of estuaries with sediments. Infilling with sediments derived from both the ocean and the land is a natural process, which typically occurs gradually over hundreds to thousands of years. This is a 'healthy' ageing process, and the ecology of the estuary evolves with the change in sediment regime. However, the rate of infilling has changed recently due to land-based human activities, resulting in prematurely aged estuaries and unbalanced ecosystems. The increased sediment input smothers the estuarine habitat, turning sand flats into mud flats, changing the distribution of animals and plants and reducing water clarity. There are repercussions on the whole estuarine food web. An 'untouched' estuarine environment is becoming more of a rarity than the Blue Whale.

Whangapoua Estuary situated on the east coast of the Coromandel Peninsula.

We all recognise the importance of conserving the Blue Whale, but what about conserving whole ecosystems? To do this we need to understand something of the way the ecosystem is structured. For example, how are sand flats, mud flats, salt marshes and their resident biota distributed? And, most importantly, how do they function in relation to physical and biological processes such as tides, waves, ecosystem productivity and species interactions?

Studying processes within an estuary tells us how the structural (eg landscape, habitat) and functional (eg predator-prey interactions, recovery dynamics) aspects of an ecosystem are interdependent.

Ecological systems are dynamic rather than static. By understanding ecosystem processes (ie how and why things change) we can recognise the full value of ecological systems and the limits to which we can push them and still maintain their values.

Now to look at increased sedimentation in estuaries and some of the processes that influence the way estuarine ecosystems respond to unhealthy rates of sediment input.

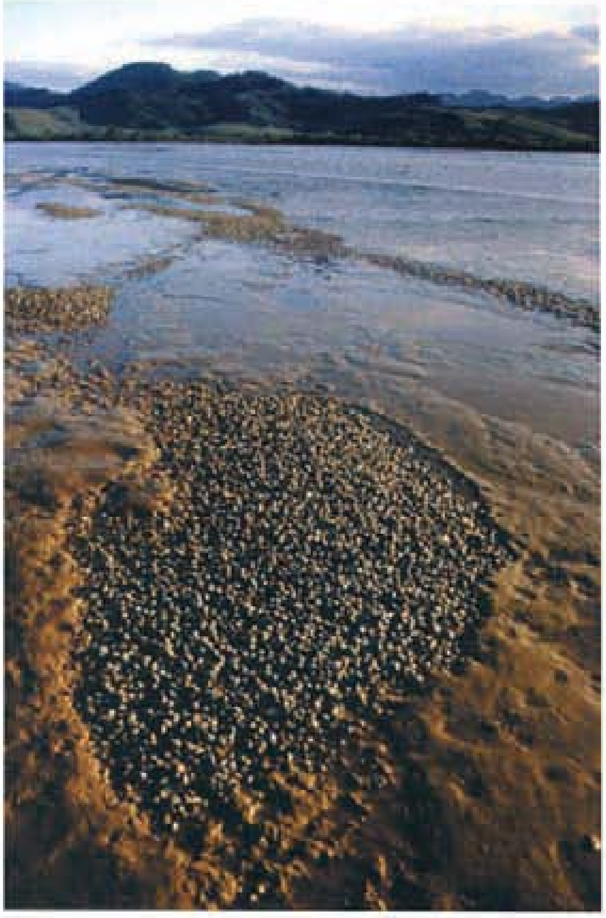


Photo 1 A cockle bed smothered by fine sediments from the catchment in Whangapoua Estuary. The sediments were washed down in a storm event and resulted in layers of clay approximately 10 cm thick covering the entire sandflat and killing underlying animals.

Causes and consequences of increased sedimentation

New Zealand has a range of environmental characteristics that intensify sedimentation of our coastal waters, such as high and sporadic rainfall, soils of volcanic origins, young and steep landforms, and a human population concentrated along the coast. Combine these factors and the result can be catastrophic. A major landslide or dump of sediment into an estuary may occur, smothering the bed of the estuary and the animals that live there (Photo 1). However, sediment may also be deposited in less extreme events. A number of small changes within a catchment can result in an increased rate of sediment input into the estuary, thereby increasing turbidity and distortion of the natural dynamics of the estuarine system. As a result the potential for changes to habitats, water quality, aesthetics and, ultimately, the biodiversity of the estuary, is increased.

Whangapoua Estuary on the Coromandel Peninsula covers a large area, and is more than 5 km wide. The mouth of the estuary leads out to the Pacific Ocean while the top of the estuary extends up into the hills of the Coromandel Peninsula. Typical of many estuarine catchments around New Zealand, the land surrounding the Whangapoua catchment is mixture of farmland, exotic forestry and regenerating native bush. As a typical estuary, Whangapoua is valuable for many different reasons. It is important recreationally for boating and aquatic activities, ecologically as a nursery and feeding ground for many coastal fish and invertebrate species, and economically as part of the coastal marine ecosystem from which we source exported seafood. As a result of rising levels of recreational pressure and the need to provide easy access to the catchment, road construction and foreshore development of the surrounding area are on the increase.

Roads are widened by slicing off a corner of a cliff (Photo 2), exposing surface clay that gets washed into streams, rivers and ultimately the estuary. One cut alone may not cause a significant difference to the estuary below, but the cut pictured was one of approximately 35 counted on a 30 km stretch of State Highway 25 passing to the south of Whangapoua Estuary. However road construction and development are not the only factors contributing to the increase in sediment runoff . Other major contributors include farming, production forest harvesting and urbanisation. These activities involve reworking large parts of the land, exposing loose clay and soil, which is then susceptible to erosion. Clay and soil ends up in waterways and eventually the receiving estuary.

Photo 2 State Highway 25, south of Whangapoua, Coromandel Peninsula.

Clay laden water flowing into the Firth of Thames after a major landslide at Tararu, (5 minutes north of Thames) January 2002.

NIWA research into estuarine and coastal sedimentation

The big question is *how do increased amounts of sediment impact on the ecology of the estuary*? If we can begin to answer this question then we can ask many others such as:

- How much sediment is too much?
- What are the most sensitive parts of the estuary?
- Which estuaries are most at risk?
- Are there other far-reaching effects of sedimentation that impact beyond the estuary into the wider coastal zone?

NIWA's research programme "Effects of Sediments on Estuarine and Coastal Ecosystems" (ESEE) is a combined effort by ecologists, oceanographers, sedimentologists and chemists to try and answer these questions and gain an understanding of how estuarine ecological processes are affected by changing rates of sedimentation. The information compiled from this research will be used as technical advice to aid environmental managers with estuarine management and conservation. The programme encompasses many aspects, dealing both with the immediate and the long-term ecological effects of sedimentation on a variety of species and habitats. It also looks at sediment transport processes within the estuarine and coastal environment. (Further information about this program can be obtained from the web site ***www.niwa.co.nz/rc/prog/esee/***)

Recent experiments by NIWA within the ESEE programme focus on what happens to the estuarine ecology when sediments are smothered with terrestrial clay. These experiments simulate the catastrophic events that occur all too often when terrestrial sediments are rapidly deposited into an estuary during a storm or flood event.

Footprint showing the depth of clay that covered the sandflat at Tararu (on the Coromandel Peninsula) after the major landslide in January 2002

Fig. 1 Habitat map of Okura Estuary. Site 1 is located in the muddier region at the top of the estuary and Site 2 is located in the sandier area towards the estuary mouth. Habitat maps are useful to help determine the sensitivity of different areas within an estuary to a known polluter and help to generalise results of experiments conducted at specific locations.

Photo 3 Sediment being dumped on the experimental plots at Okura estuary via helicopter.

How do we begin to understand the effects of excess sediment on estuaries? - a case study from Okura estuary

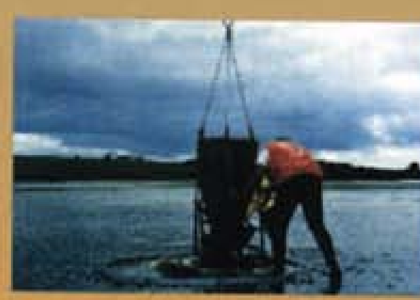
Apart from rushing off to an estuary after heavy rainfall with monitoring gear, we can use controlled experiments to quantify the response of biological, physical and chemical processes to catastrophic events. Experiments can provide small-scale mimics of actual events and enable us to build a picture of response to and recovery from dramatic habitat change. Such a controlled experiment was run in collaboration with the Auckland Regional Council (ARC) in Okura Estuary, north-east of Auckland. The experiment had two main aims:

1. To identify the critical depth of sediment deposition that represents a significant ecological threat to the estuary; and
2. To help determine the sensitivity of different areas of the estuary to changes in the sediment layer.

Methods

Clay was obtained from a sediment retention pond used for the recent motorway extension in the Okura catchment area, and mixed into a slurry. This was transported to the estuary via helicopter (Photo 3) and dumped into constraining rings at depths of 3, 6 or 9 cm on the intertidal sand flat. These clay depths were chosen on the basis of previous laboratory experiments and observations of real sedimentation events, such as the one in Whangapoua estuary (Photo 1).

Guiding the clay into the plots during the Okura experiment



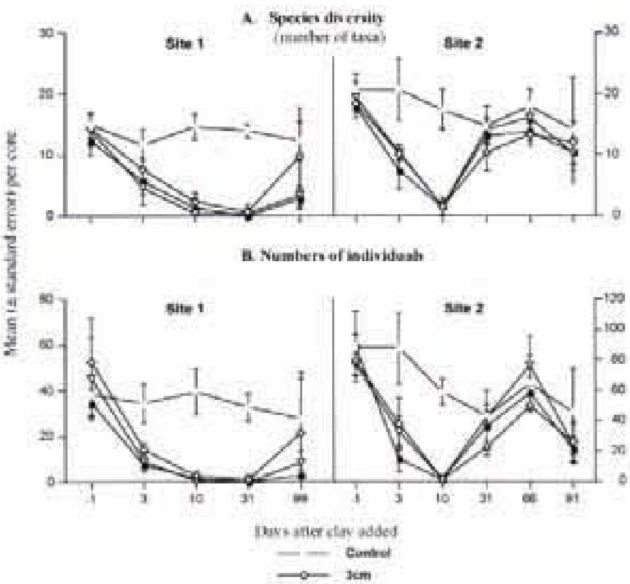


Fig. 2 Effect of clay deposition on species diversity (A) and the number of individuals (B) at Site 1 (on left) and Site 2 (on right) over the recovery period. Note the different scales used on the Y-axes for the number of individuals. The different clay depths are represented by different symbols. Sampling began one day (-1) before the clay slurry was dumped onto the treatment sites and continued beyond 3 months. Note that x–axis is different for the two sites and not to scale.

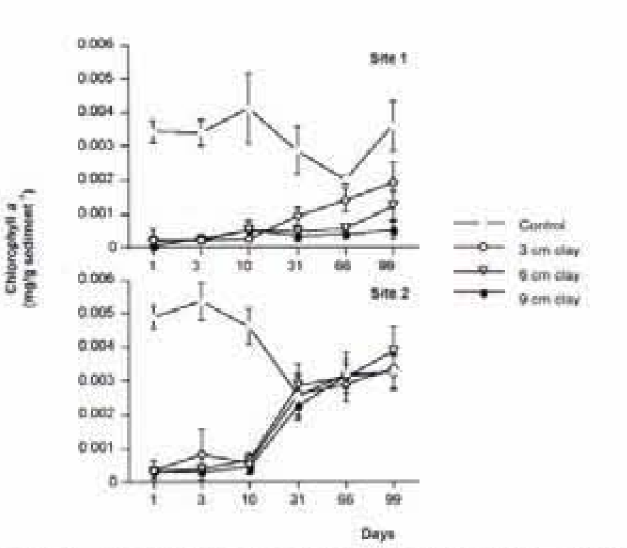


Fig. 3 Effect of clay deposition on sediment chlorophyll *a* concentrations in the experimental plots at site 1 and 2 over time. Values expressed as the mean ± standard error. Note that x–axis is not to scale.

The experiment was replicated at two sites with different sediment characteristics (Figure 1). Site 1 had muddier sediments, less diverse benthic communities, fewer bivalves and more mud burrowing crabs than Site 2. Having two experimental sites meant that important information on the relative sensitivities of different habitats within the estuary could be determined. The sites also had different levels of exposure to wind and waves, and these were measured using a Dobie wave gauge. Waves are an important physical factor that influences the rate of recovery of sand flats from sedimentation. They not only break-up clay layers but are also involved in the transport of animals and sediments.

Results from the Okura experiments - Understanding the recovery of a sand flat community after disturbance by sediments

Biological and physical parameters were measured immediately before the clay was deposited then a number of times over the following months. The information collected included measurements of macrofauna (number of both individuals and species present), the depth of the clay layer and chlorophyll *a* levels in the sediments of the experimental plots. The amount of chlorophyll *a* in the sediments is an important biological characteristic as it reflects the density of microphytobenthos (microscopic plants). These provide an important food resource for macrofauna and can also affect how easily sediment is eroded and transported.

Macrofaunal response

Macrofauna were sampled in the plots and in adjacent undisturbed areas to enable us to determine changes in the benthic community as a result of clay deposition. Site 1 has a naturally lower diversity of macrofauna than Site 2 due to its location and sediment characteristics. At both sites the samples taken from undisturbed areas show little change in numbers of individuals or number of species over time (Fig. 2). However, from our observations we concluded that the critical depth of clay that caused death was less than 3 cm, as at least a 50% decline was observed in all clay plots by day 3, and by day 10 a complete die-off was recorded.

Although there were differences among species, most polychaete worms and bivalves were unable to move up through even 3 cm of clay. Also a clay layer of 3 cm may have prohibited bivalves from extending their siphons up to the sediment surface to obtain oxygen and food. Crabs were the only animals able to survive and climb up through the clay. Crabs also moved into the plots from outside, and their burrowing activities aided the reworking of the clay into the old sediment (Photo 4).

Photo 4 Mud crabs (*Helice crassa*) are important inhabitants of estuaries and play a very important role, as their burrowing activities result in the break-up mobilisation of sediments.

Signs of recovery from the 3 cm plots began after 31 days at site 1 (Figure 2). At Site 2, signs of recovery were beginning after only 10 days. A storm event caused waves greater than 40 cm high at Site 2 on day 30 (these were recorded by the Dobie wave gauge). The waves probably broke the hardened clay apart and accelerated the rate of recovery. Recovery at Site 1 was not aided by this storm, due to its more sheltered location in the upper estuary.

***Chlorophyll* a**

Levels of chlorophyll *a* in the clay patches were very low compared to those in the undisturbed plots (Figure 3). This meant there was less food available in the clay layer, so animals not only had to cope with a smothering anoxic effect (ie no oxygen) but also a drop in food supply. At Site 1, chlorophyll *a* concentrations in the sediment increased gradually, in the weeks following the clay addition, but had still not reached the levels of the undisturbed sediments after 99 days. At Site 2 there was a dramatic recovery of chlorophyll *a* levels after the storm washed away the clay layers.

Overview

We have reported only a few of the important characteristics that illustrate the response of benthic communities to a catastrophic sediment dump.

This experiment has shown that a covering of only 3 cm of clay can cause a die-off of macrofauna (apart from crabs) in an estuary like Okura, and that the recovery of an entire complex community can take in excess of three months. We also observed that animals moving into the plots were mainly juveniles. The actual recovery period required to re-establish a complex community consisting of both juvenile and larger adult macrofauna at Site 2 has taken approximately six months, with Site 1 still recovering after 18 months.

This experiment is one of a series of three conducted by NIWA with the aim of learning more about the effects of sedimentation. The experiment was replicated in both Whangapoua and Whitianga estuaries in order to determine whether similar results would occur. Repeating experiments in different locations is important to help us better understand which processes influence recovery and how these vary between different estuarine systems. Thus, when we selected locations to repeat the experiment, we tried to vary a number of the factors that we think will influence recovery. In this case we considered macrofauna-community complexity, how much effect wind and waves have on the sand flats, geography of the surrounding area, tidal differences, and overall differences in physical and biological processes within a particular estuary. For example, Whitianga has a fast tidal flow and large populations of burrowing crabs, while Whangapoua has a large water surface area exposed to prevailing winds, and a less urbanised catchment.

These experiments help us predict what may occur during a natural sedimentation event. However, they have been conducted on a relatively small scale, and therefore when a larger natural event occurs, recovery may be much slower.

Okura Estuary seen from near the mouth.

Tairua estuary on the east coast of the Coromandel Peninsula, flanked by the settlements of Pauanui (left) and Tairua (right).

Conclusion

The Blue Whale species needs a sound conservation strategy, but if the critical aspects of its ecosystem are not understood we may not be able to correctly manage the conservation of this one species. This understanding is equally important in relation to the individual animals and environments within any given estuary. Increased sedimentation in an estuary has a significant effect on the entire system. As we learn more about sedimentation and its effects, we become better equipped to predict and ultimately prevent detrimental outcomes. A combination of the knowledge gained from these experiments and future work will help close the information gap and assist managers in making informed decisions about the management of our estuarine ecosystems. Informed management not only benefits the estuary but may also assist conservation of the entire marine ecosystem.

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