Davidson Environmental Limited

Biological monitoring of the ferry route in Tory Channel and Queen Charlotte Sound: 1995-2010

Research, survey and monitoring report number 643

A report prepared for:

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Summary

1. High speed ferries operated intermittently between Picton and Wellington from late 1994 to mid 2005. A variety of modern conventional ferries have travelled the same route since 1962.
2. When fast ferries first arrived, many Sounds residents complained of a dramatic increase in wave size. It was also argued that fast ferries had an adverse impact on biological communities in sheltered shores. Following a hearing initiated by a community group called "Save the Sounds, Stop the Wash", The Environment Court stated that an adverse biological impact could not be proven due to a lack of before fast ferry data and that fast ferries were forming a "new equilibrium" comprising both conventional and fast speed vessels (NZ Planning Tribunal, 1995).
3. On December 15th 2000, a Navigation Bylaw restricting fast ferries to a maximum speed of 18 knots inside the Sounds was implemented. The Bylaw aimed to reduce waves produced by fast ferries using a "wash rule". New intertidal and subtidal bedrock monitoring sites were sampled prior to the introduction of the Bylaw.
4. This report compares intertidal and subtidal bedrock and cobble-boulder biological data from sites along the ferry route (impact sites) and away from the ferry route (control sites). Sites were all located in the relatively sheltered waters of Tory Channel and Queen Charlotte Sound.
5. The present study documents a widespread and often dramatic recovery of biological communities at impact intertidal and subtidal cobble-small boulder shore as well as intertidal and shallow subtidal bedrock shores following the Bylaw implementation to slow fast ferries to 18 knots. As these changes did not occur at control sites, the only plausible explanation is a reduction in wave energy. It took 15 years of monitoring to demonstrate that the concerns voiced by local Sounds residents during the summer of 1994-95 were correct and that the "new equilibrium" was in fact representative of a major adverse biological environmental impact.
6. At particular subtidal bedrock sites, the recovery surpassed control levels; however, for intertidal shores, the recovery peaked in 2005-2006. The density of invertebrates at intertidal cobble shores and intertidal bedrock shores steady declined after 2005-2006. This recovery reversal and the failure of intertidal shores to reach control levels were most likely due to waves generated by conventional ferries. This subsequent decline in species numbers and densities at these intertidal shores coincided with the introduction of the largest conventional ferry in late 2005.
7. It is recommended that biological monitoring is continued to assess the scale of the declining trend recorded at some intertidal sites and to follow the recovery at subtidal shores.

1.0 Introduction

The present study investigates intertidal and subtidal bedrock and cobble-boulder communities located along the ferry route (impact sites) and distant to the ferry route (control sites) in Tory Channel and Queen Charlotte Sound.

A variety of monitoring studies have investigated the impact of fast ferries travelling at high speed (Davidson 1995, 1996, 1997, 2000). On December 15th 2000, a Navigation Bylaw restricting fast ferries to a maximum speed of 18 knots was implemented. The Bylaw aimed to reduce the size of waves produced by high speed ferries using a “wash rule” (Croad and Parnell 2002). A reduction in wave size theoretically provided the opportunity for biological communities located along the ferry route to recover from the period when high speed ferries operated without speed restrictions.

In response to this decision, additional data were collected immediately prior to the start of the Bylaw (Davidson 2002). For the first time since the start of high speed ferries, quantitative data for control and impact intertidal and shallow subtidal bedrock shores were collected. An additional intertidal cobble site at Onapua, Tory Channel and two subtidal cobble sites were also added prior to the Bylaw (Davidson 2002).

A report presenting continued monitoring as well as the first two years of monitoring the new sites following the 18 knot Bylaw was produced by Davidson (2002) and another report was produced after five years of the Bylaw (Davidson and Richards 2005). During the period between the initiation of the Bylaw (December 2000) and the Davidson and Richards (2005) report, both high speed ferries ceased operation leaving only conventional ferries.

Davidson and Richards (2005) reported that during the first five years after the Bylaw, many but not all intertidal and shallow subtidal sites showed evidence of a recovery from their pre-2000 levels. The authors stated that “recovery has occurred at too many sites and for too many species to be a coincidence”.

The present report provides an update of biological data collected from previously sampled bedrock and cobble/boulder shores from 2006 to 2010 (Table 1). The report concludes with comments on biological changes over the study period in relation to ferry passage and the impact of fast ferries travelling at unrestricted speeds prior to the Bylaw.

Table 1. Summary of sample events and days elapsed following the start of the study.

Date	1995	1995	1995	1995	1995	1995	1995	1995	1996	1996	1996	1997	1997	1997	1997	1999	2000	2000	Bylaw	2001	2002	2002	2004	2005	2006	2007	2008	2009	2010
Intertidal cobble																													
Date	7-Mar	27-Jul		5-Oct	30-Oct	20-Nov	7-Dec		11-Jan	27-Feb	21-Nov	23-Jan	6-May	13-Aug	10-Dec	28-Apr	29-Feb	27-Nov	15-Dec	28-May	12-Feb	3-Dec	20-Apr	22-Feb	27-Feb	29-Mar	18-Feb	5-Feb	22-Feb
Time series (days)	0	142.00		212.00	237.00	258.00	275.00		310.00	357.00	625.00	688.00	791.00	890.00	1009.00	1513.00	1820.00	2092.00	1968.00	2274.00	2534.00	2828.00	3332.00	3640.00	4010.00	4405.00	4731.00	5084.00	5466.00
Subtidal cobble (paua, kina)																													
Date	25-Feb	3-Aug	19-Sep		30-Oct	20-Nov	7-Dec		11-Jan	27-Feb	21-Nov	23-Jan	6-May	13-Aug	10-Dec	28-Apr	29-Feb	27-Nov	15-Dec	28-May	12-Feb	3-Dec	20-Apr	22-Feb	27-Feb	29-Mar	18-Feb	5-Feb	22-Feb
Time series (days)	0	159.00	206.00		247.00	268.00	285.00		320.00	367.00	635.00	698.00	801.00	900.00	1019.00	1523.00	1830.00	2102.00	1961.00	2284.00	2544.00	2838.00	3342.00	3650.00	4020.00	4415.00	4741.00	5094.00	5476.00
Cast study																													
Date	27-Jul	17-Aug	19-Sep	10-Oct	30-Oct	20-Nov	7-Dec	29-Dec	11-Jan	27-Feb	21-Nov	23-Jan	6-May	13-Aug	10-Dec	28-Apr	29-Feb	27-Nov	15-Dec	28-May	12-Feb	3-Dec	20-Apr	22-Feb	27-Feb	29-Mar	18-Feb	5-Feb	22-Feb
Time series (days)	0	21.00	54.00	75.00	95.00	116.00	133.00	155.00	168.00	215.00	483.00	546.00	649.00	748.00	867.00	1371.00	1678.00	1950.00	1947.00	2132.00	2392.00	2686.00	3190.00	3498.00	3868.00	4263.00	4589.00	4942.00	5324.00
Subtidal cobble (cats-eye)																													
Date						20-Nov	7-Dec		11-Jan	27-Feb	21-Nov	23-Jan	6-May	13-Aug	10-Dec	28-Apr	29-Feb	27-Nov	15-Dec	28-May	12-Feb	3-Dec	20-Apr	22-Feb	27-Feb	29-Mar	18-Feb	5-Feb	22-Feb
Time series (days)						0.00	17.00		52.00	99.00	367.00	430.00	533.00	632.00	751.00	1255.00	1562.00	1834.00	1835.00	2016.00	2276.00	2570.00	3074.00	3382.00	3752.00	4147.00	4473.00	4826.00	5208.00
Intertidal bedrock																													
Date																		27-Nov	15-Dec	28-May	12-Feb	3-Dec	20-Apr	22-Feb	27-Feb	29-Mar	18-Feb	5-Feb	22-Feb
Time series (days)																		0.00	18.00	182.00	442.00	736.00	1240.00	1548.00	1918.00	2313.00	2639.00	2992.00	3374.00
Subtidal bedrock																													
Date																		27-Nov	15-Dec	28-May	12-Feb	3-Dec	20-Apr	22-Feb	27-Feb	29-Mar	18-Feb	5-Feb	22-Feb
Time series (days)																		0.00	18.00	182.00	442.00	736.00	1240.00	1548.00	1918.00	2313.00	2639.00	2992.00	3374.00

2.0 Background information

2.1 Marlborough Sounds geology

The Marlborough Sounds are a series of “drowned” river valleys formed along major fault zones, such as the Queen Charlotte Fault controlling Grove Arm and Queen Charlotte Sound. A number of major faults are mapped in the Picton-Waikawa area, with a known active structure extending from The Elevation along the eastern side of Waikawa Bay and probably merging with the Queen Charlotte Fault system. The Sounds area lies above the southern limit of the subducting Pacific Plate, which is moving westwards beneath the Indian-Australian Plate at about 50mm/year.

The rocks forming the north-eastern part of the Marlborough Sounds, including the ferry corridor from Picton through Tory Channel to Cook Strait, consist of low rank schists and greywacke-mudstone sequences. The rocks of the Marlborough Sounds are typically weathered to depths of more than 10m, giving rise to a yellow-brown colouration with the extensive development of clay and silt. A characteristic red-brown weathering with iron oxides in a clay matrix occurs in a number of localities, including Moioio Island in Tory Channel, and this is interpreted to indicate a landscape at least as old as the Last Interglacial (c.100 ± 20 ka). Regional submergence, rather than uplift, has been suggested to explain the development of the Sounds “block”, and this could be related to a major fault structure controlling Cook Strait.

Global sea levels have fluctuated by as much as 150m in the past 2 million years accompanying glacial and interglacial climates, with the most recent period of significant sea-level lowering occurring during the last glaciation. Sea-level only reached its present elevation between 6,000 and 7,000 years ago, following a period of rapid rise, and the present landforms along Queen Charlotte Sound and Tory Channel reflect adjustment to this relatively new base-level and establishment of a state of quasi-equilibrium.

2.1 Historical use of the Sounds by ferries

Vessels travelling between Wellington and Picton have provided the principal sea link between the two main islands of New Zealand for all of the 20th Century (Kirk and Newton, 1978). The modern and frequent inter-island ferry service using conventional ships started in 1962 and during the 1970s there were complaints of adverse effects caused by these vessels (Kirk and Single, 2000), particularly with respect to:

- Beaches close to the sailing line of the ferries have become coarser and steeper.
- Rapid movement of material along [some] beaches causing erosion from source areas and deposition elsewhere on the foreshore.
- Apparent increase in the slipping of basal hill slope deposits.
- Apparent increase in siltation of near-shore and offshore areas (Valentine 1982).

In a geomorphological study of the Tory Channel, Newton (1977) concluded that the inter-island ferry service added a significant input of wave energy to the natural wave climate and that changes in shoreline deposits were due to systems seeking a new equilibrium with the wave energy input.

Because of the findings by Newton (1977), voluntary speed restrictions were imposed on ferries passing through Tory Channel. Kirk (1978) carried out measurements during March 1978, concluding that a reduction in speed through the narrower sections of the Channel, combined with specific engineering works carried out by Marlborough Harbour Board, had eliminated the problem of shoreline conditions. The speed restrictions however, were temporary.

The new generation high speed ferries were introduced onto the route in the summer of 1994/5, when the Condor 10 and the Albayzin began operating alongside conventional ships. Environmental effects perceived by the community resulted in the 1995 Planning Tribunal hearing, with the MDC seeking certain declaratory judgements, and a community group (Save the Sounds – Stop the Wash), the Department of Conservation and the local iwi (Te Atiawa) seeking enforcement orders to slow the fast ferries. Since the first introduction, five different high speed ferries have operated at various times, in most years only offering a service during the summer months.

The Albayzin had a very short period of operation during late 1994 - early 1995 due to mechanical issues (Appendix 1). The Incat 050 or TopCat was its replacement and operated an all-year service from mid 1999 to late 2000. The Condor 10 operated during the summer season from late 1994 to mid 1999. It was replaced by the Condor Vitesse (Incat 044), operating for one summer season in 1999-2000. The Incat 057 (Lynx) operated all year from late 2000 to late 2004 when it was replaced by Incat 046. Incat 046 operated for one summer in 2004-2005 then ceased operation. No high speed ferries have operated in the Marlborough Sounds since this time (Appendix 1).

During the period when high speed ferries operated, a variety of conventional ferries have travelled the same route. The Aratika ceased operation in early 1999 and was replaced by the Aratere in early 1999. The Arahunga ceased operation in early 2001 and was replaced by Challenger (Kaitaki) in mid 2005. A number of conventional ferries operated by Strait Shipping have also travelled the same route. These have included the Straitsman (late 1993-late 2003), Suilven (late 1995-mid 2004), and Santa Regina (late 2002 onwards).

3.0 Methods

Following the report by Davidson and Richards (2005), data have been collected on five occasions ending in 2010. Sampling occurred at (1) cobble-small boulder and (2) bedrock shores (see below).

1. Cobble/small boulder
    - Intertidal (density of invertebrates under and on substrata).
    - Shallow subtidal density of paua, kina and cats-eye snails.
    - Intertidal (relative abundance of invertebrates recently cast ashore by waves).
2. Bedrock
    - Intertidal (density of particular invertebrate species).
    - Shallow subtidal (invertebrate density from two depth strata).

3.1 Cobble-small boulder shores

All cobble/small boulder control sites were located in Queen Charlotte Sound east of Dieffenbach Point. These areas of Queen Charlotte Sound are only occasionally used by ferries and large ships under particular circumstances (e.g. cruise-liners, safety issues for inter-island ferries). Impact sites were located along Tory Channel and the southern shoreline of central Queen Charlotte Sound between Dieffenbach Point and Picton Point.

Intertidal and shallow subtidal sites were characterised by relatively uniform cobble, pebble and small boulder substrata. Intertidal shores were relatively narrow (i.e. 10 m to 20 m wide from high water to low water), gently sloping in gradient, with the shallow subtidal often represented as an extension of intertidal habitats. Sites were spread widely in location to represent a large range of shore aspects and exposures subject to ferry and natural wave climates. Sites were located on shores with comparable topography and substratum in an effort to reduce environmental variability.

3.1.1 Intertidal cobble-small boulder (invertebrate density)

Apart from one impact site (Onapua: 2000 to 2010), all intertidal cobble-small boulder control and impact sites were sampled between 1995 and 2010 (Figure 1, Table 2). At mid-tide (approximately 0.7 m to 1 m above spring low water) and near low tide (approximately 0.2 m to 0.4 m above s.l.w.), a steel peg was driven into the substrata to enable re-sampling of the same tidal height on each occasion.

Within each tidal zone, cobble-small boulders (200 mm to 300 mm length) were haphazardly selected and individually placed on a white tray. All macroinvertebrates living on each rock and on the substratum under each rock were counted. Data recorded from “on rocks” and from “under rocks” were combined for the purposes of the present study.

The rocks selected for study were from the size category shown to regularly move in areas subjected to ferry wakes (Davidson 1995; Grange et al. 1995; Gillespie 1996). Rocks partially buried or compacted into the substratum were not sampled as they provided no animal habitat on their underside. Data were categorised into (a) number of all invertebrate species and (b) number of individual molluscs.

Table 2. Intertidal invertebrate sample sites in Queen Charlotte Sound and Tory Channel sampled from 1995 to 2010. Note: Onapua was sampled from 2000 to 2010.

Treatment	Substratum	Site	Coordinates (NZMG)	Aspect
Control	Cobble	Spencer Bay	2609703.6,6001367.4	Southward
Control	Cobble	Blumine sth	2614738.9,6002236.7	Southward
Control	Cobble	Arapawa	2615808.1,6001971.2	Northward
Control	Cobble	Blumine nth	2613683.4,6004601.8	Northward
Impact	Cobble	Picton Pt.	2596845.9,5994203.8	Northward
Impact	Cobble	Arrowsmith	2610805.3,5995022.5	Northward
Impact	Cobble	Onapua	2608711.0,5994283.4	Northward
Impact	Cobble	Deep Bay	2615648.6,5997145.0	Southward

3.1.2 Subtidal cobble-small boulder (black-foot paua, kina and cats-eye density)

Kina and black-foot paua were sampled from five control and five impact sites (Figure 2, Table 3). Most sites were sampled from 1995 to 2010, apart from Spencer Bay and Blumine south (both 1997-2010) and Monkey Bay and Arrowsmith (both 2000-2010).

At each site, the subtidal shore between 0.5 m to 1 m depth below low water was sampled using SCUBA. The subtidal sample zone was marked using 600 mm steel stake driven into the substratum. On each sample occasion, either five or six random 10 x 1 m quadrats were sampled by over-ending a 1 m^2 quadrat parallel to the shoreline. Within each quadrat, the number of urchins (*Evechinus chloroticus*) and black-foot paua (*Haliotis iris*) were recorded. Cats-eye snails (*Turbo smaragdus*) were counted from eight to ten 1 m^2 predetermined randomly assigned quadrats as a subset of the 50-60 total kina and paua quadrats sampled at each site.

Table 3. Kina, cats-eye and black-foot paua subtidal cobble sample sites in Tory Channel and Queen Charlotte Sound (1995 to 2010). Note: Spencer Bay and Blumine south were sampled from 1997 to 2010, while Monkey Bay and Arrowsmith were sampled from 2000 to 2010.

Treatment	Substratum	Site	Coordinates (NZMG)	Aspect
Control	Cobble	Double Bay	2610539.3,5998962.8	Northward
Control	Cobble	Spencer Bay	2609703.6,6001367.4	Eastward
Control	Cobble	Blumine sth	2614738.9,6002236.7	Southward
Control	Cobble	Clark Pt	2618503.9,6007074.1	Northward
Control	Cobble	Long Is	2616471.7,6007830.5	Northward
Impact	Cobble	Monkey Bay	2601655.1,5995406.1	Northward
Impact	Cobble	Dieffenbach west	2605216.9,5996055.4	Northward
Impact	Cobble	Arrowsmith	2610805.3,5995022.5	Northward
Impact	Cobble	Te Weuweu	2612227.8,5994689.5	Eastward
Impact	Cobble	Onapua	2608711.0,5994283.4	Eastward

3.1.3 Cast invertebrate presence-absence and density (intertidal)

Subtidal invertebrates recently cast onto the intertidal zone were counted from seven control sites in eastern Queen Charlotte Sound and three impact sites (two in Tory Channel and one west of Dieffenbach Point) (Figure 3, Table 4).

Impact and control sites were sampled from 1995 to 2010, excluding control sites located at Snake Point and Blumine (north and south), sampled from 1997 to 2010. At each site, permanent 4 m x 4 m quadrats were installed extending down the shore from the upper boundary or drift line of the intertidal shore. Each quadrat corner was marked using a 600 mm steel peg driven into the substratum. White spray paint was also used to mark the upper terrestrial shore adjacent to quadrats to ensure they could be relocated if pegs were washed away. Quadrats were separated by a minimum of 10 m distance.

On each sample occasion, a search for recently dead or dying invertebrates was conducted within each quadrat. Only recently dead or dying animals on the sediment surface or within surface drift material (e.g. tree branches and seaweed) were counted. "Recently dead or dying animals" were defined as those having flesh or particular body parts present that would normally degrade or disappear with time spent on the shore (e.g. kina spines still present on test, remnant flesh present on chiton shells). All animals recorded from quadrats were removed so they were not counted in subsequent visits. Animals living in their natural habitats within quadrats were not included in counts.

Table 4. Intertidal cobble cast invertebrate sample sites in Tory Channel and Queen Charlotte Sound (1995-2010). Note: Blumine (north and south) and Spencer Bay were sampled 1997-2010.

Treatment	Substratum	Site	Coordinates (NZMG)	Aspect
Control	Cobble	Bay of Many Coves	2608490.2,6000571.6	Northward
Control	Cobble	Double Bay	2610539.3,5998962.8	Northward
Control	Cobble	Spencer Bay	2609703.6,6001367.4	Eastward
Control	Cobble	Blumine sth	2614738.9,6002236.7	Southward
Control	Cobble	Blumine nth	2613568.8,6004405.5	Northward
Control	Cobble	Clark Pt.	2618503.9,6007074.1	Northward
Control	Cobble	Long Is.	2616438.6,6007679.5	Northward
Impact	Cobble	Dieffenbach west	2605216.9,5996055.4	Northward
Impact	Cobble	Te Weuweu	2612227.8,5994689.5	Eastward
Impact	Cobble	Onapua	2608711.0,5994283.4	Eastward

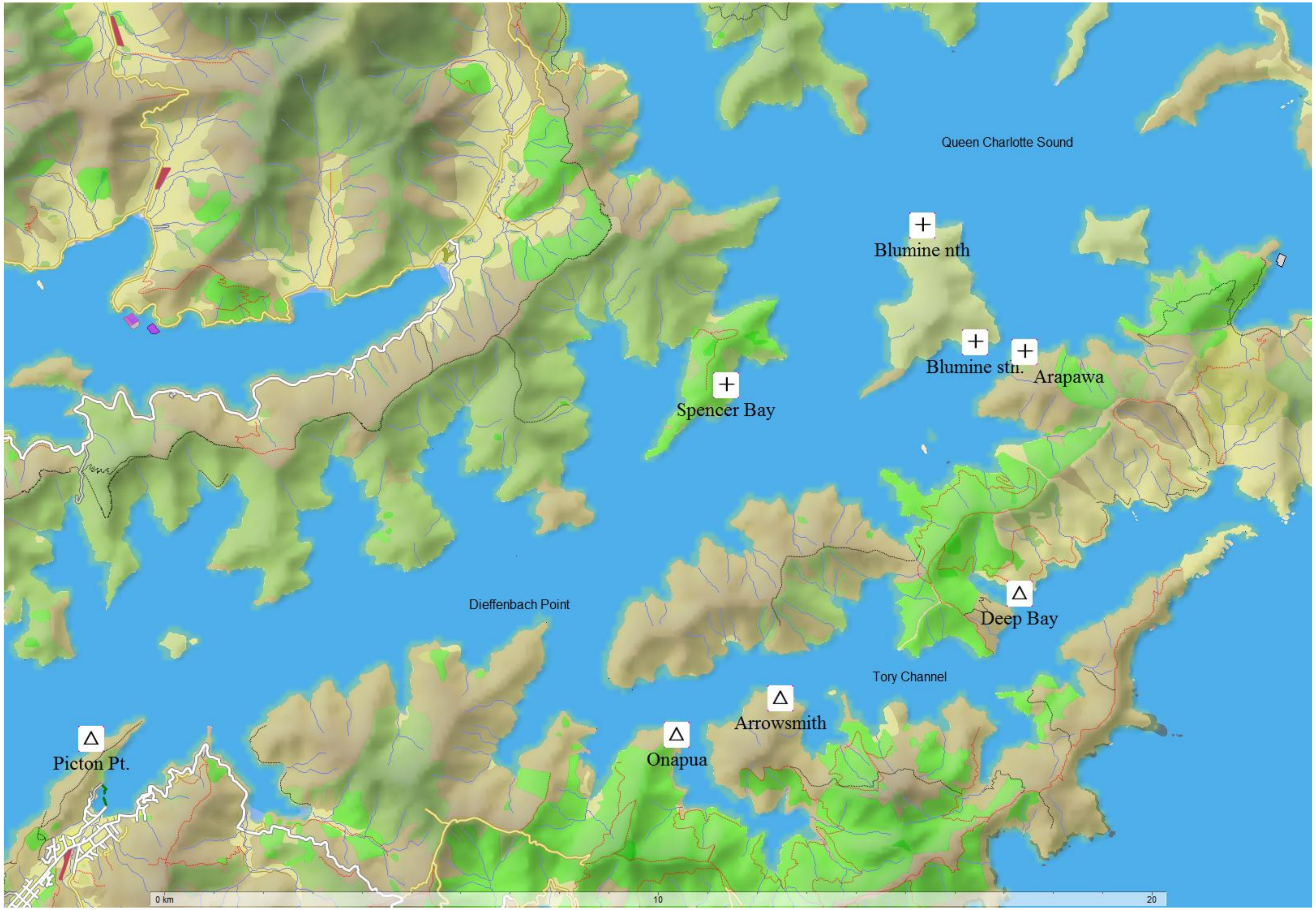

Figure 1. Location of intertidal cobble invertebrate sample sites. Control = crosses, impact = triangles.

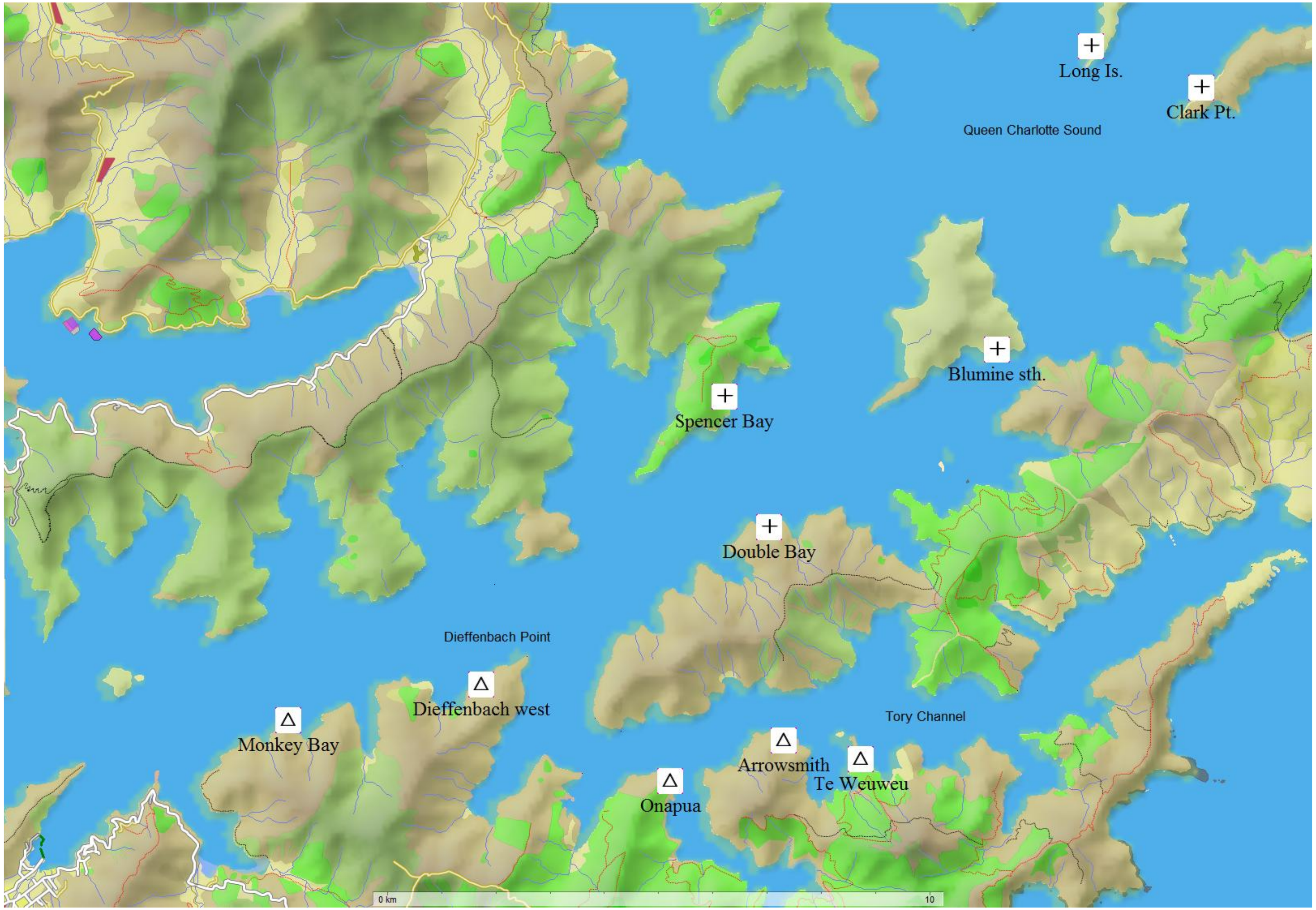

Figure 2. Location of subtidal cobble kina, cats-eye and black-foot paua sample sites. Control = crosses, impact = triangles.

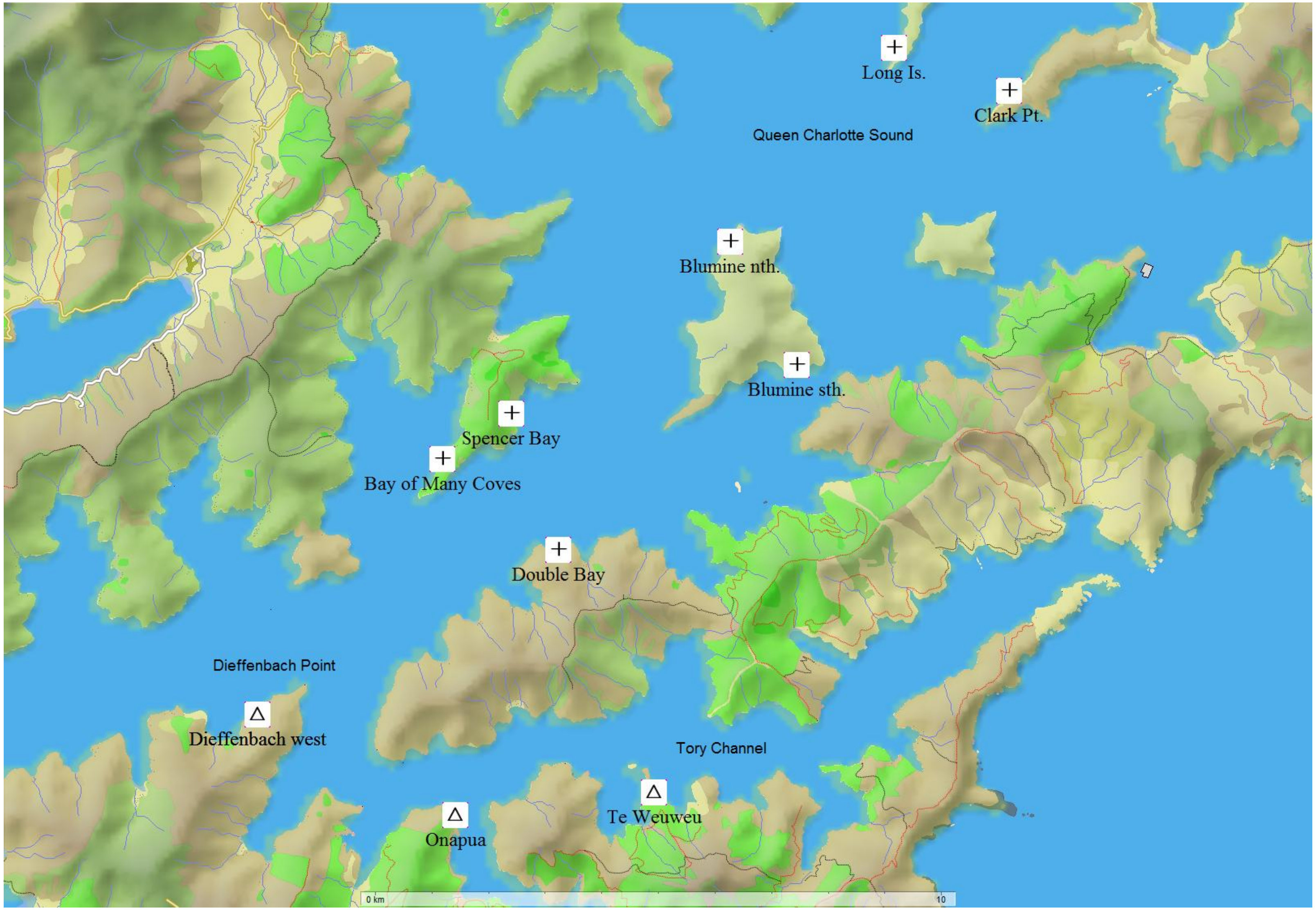

Figure 3. Location of intertidal cast invertebrate sample sites. Control = crosses, impact = triangles.

3.2 Bedrock shores

Apart from one bedrock control site in inner Queen Charlotte Sound (Houhou Point), all control sites were located in Queen Charlotte Sound east of Dieffenbach Point. At Houhou Point, a small lift and fall in water height was observed following the passage of ferries into Picton Harbour, however, no breaking waves were ever observed at this site. Impact bedrock sites were located along the northern and southern shoreline of Tory Channel and central Queen Charlotte Sound between Dieffenbach Point and Allports Island.

Intertidal bedrock shores are relatively narrow (i.e. < 10 m width from high water to low water) and were represented by either steep or gently sloping topography. A comparable number of impact and control sites of each shore gradient were selected for study. Sites were spread widely in location to represent a large range of shore aspects and exposure to ferry and natural wave climates.

3.2.1 Intertidal bedrock (invertebrate density)

Six control and eight impact intertidal bedrock sites were sampled from inner and outer Queen Charlotte Sound and Tory Channel from 2000 to 2010 (Table 5, Figure 4). Bedrock shores were sampled on 10 occasions after the implementation of the 18 knot restriction and one occasion before the bylaw (November 2000).

Samples were collected from between low water and mid-tide (i.e. 0 m to 0.5 m above s.l.w.). At each site, conspicuous "mobile" molluscs were counted from 10 haphazardly deployed 1 m^2 quadrats. Only molluscs that were easily detached from the substratum were counted. Molluscs anchored to bedrock such as limpets were not sampled.

3.2.2 Subtidal bedrock (invertebrate density)

A total of five control and six impact subtidal bedrock sites were sampled from inner and outer Queen Charlotte Sound and Tory Channel (Figure 5). Two depth strata were sampled (0 m to 0.5 m and 1.5 m to 2 m below s.l.w.). While conducting fieldwork, adjustments for the level of the tide were made to ensure samples were collected from consistent depths.

Two methods were adopted at each site and depth strata. Firstly, a count of predetermined macroinvertebrates was collected from 10 haphazardly deployed (1 m^2) quadrats in each depth strata. Species selected included cats-eye, topshells, rock shells, whelks, 11 arm seastar, urchins, cushion seastars, paua, and sea cucumber.

Table 5. Intertidal bedrock sites in Tory Channel and Queen Charlotte Sound (2000 - 2010).

Treatment	Substratum	Site	Coordinates (NZMG)	Aspect
Control	Bedrock	Houhou Pt.	2591285.8,5994226.5	Southward
Control	Bedrock	Snake Pt.	2608106.3,6000046.7	Northward
Control	Bedrock	Double Bay	2610804.6,5999109.6	Northward
Control	Bedrock	Umuwheke Pt.	2611905.4,5999380.6	Northward
Control	Bedrock	KuraKura Pt.	2610482.6,6001779.5	Southward
Control	Bedrock	Blumine (south)	2614840.6,6002163.3	Southward
Impact	Bedrock	Allports Is.	2598561.8,5995852.2	Southward
Impact	Bedrock	Golden Pt.	2600238.3,5996947.3	Northward
Impact	Bedrock	Monkey Bay	2601707.2,5995393.4	Northward
Impact	Bedrock	Kahikatea Bay	2603788.9,5996224.7	Northward
Impact	Bedrock	Ruaomoko Pt.	2607277.3,5995581.2	Westward
Impact	Bedrock	Arrowsmith Bay	2610748.8,5995186.2	North-eastward
Impact	Bedrock	Ngaruru Bay	2613215.7,5995987.8	Southward
Impact	Bedrock	Tory Channel	2614971.2,5995903.1	Southward

The second method involved collection of density data for three selected species from the same depth strata using 3 or 4 sets of contiguous 20 x 1 m^2 quadrats. Contiguous quadrats were installed by over-ending a 1 m^2 quadrat 20 times. Macroinvertebrates selected for investigation were large species that were often present at subtidal sites, but were patchily distributed. Key species selected were 11 arm seastar (*Coscinasterias muricata*),kina or urchin (E. *chloroticus*), and sea cucumber (*Stichopus mollis*). These species were also sampled sing the first method of 1 m^2 quadrats as a comparison.

Table 6. Subtidal bedrock sites in Tory Channel and Queen Charlotte Sound (2000 - 2010).

Treatment	Substratum	Site	Coordinates (NZMG)	Aspect
Control	Bedrock	Houhou Pt.	2591285.8,5994226.5	Southward
Control	Bedrock	Snake Pt.	2608106.3,6000046.7	Northward
Control	Bedrock	Double Bay	2610804.6,5999109.6	Northward
Control	Bedrock	Umuwheke Pt.	2611905.4,5999380.6	Northward
Control	Bedrock	KuraKura Pt.	2610482.6,6001779.5	Southward
Impact	Bedrock	Allports Is.	2598561.8,5995852.2	Southward
Impact	Bedrock	Golden Pt.	2600238.3,5996947.3	Northward
Impact	Bedrock	Monkey Bay	2601707.2,5995393.4	Northward
Impact	Bedrock	Kahikatea Bay	2603788.9,5996224.7	Northward
Impact	Bedrock	Arrowsmith Bay	2610748.8,5995186.2	North-eastward
Impact	Bedrock	Ngaruru Bay	2613215.7,5995987.8	Southward

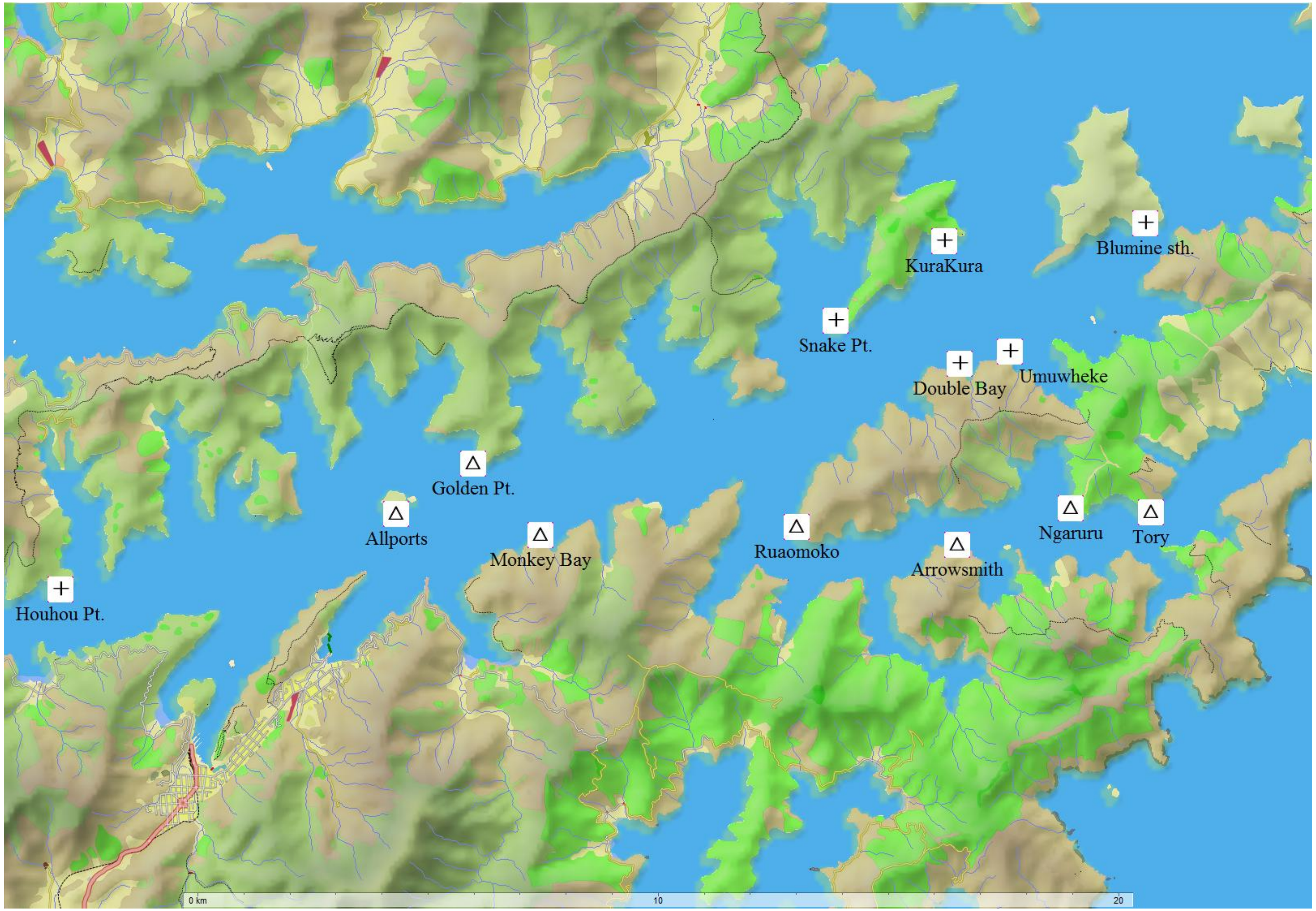

Figure 4. Location of intertidal bedrock sample sites. Control = crosses, impact = triangles.

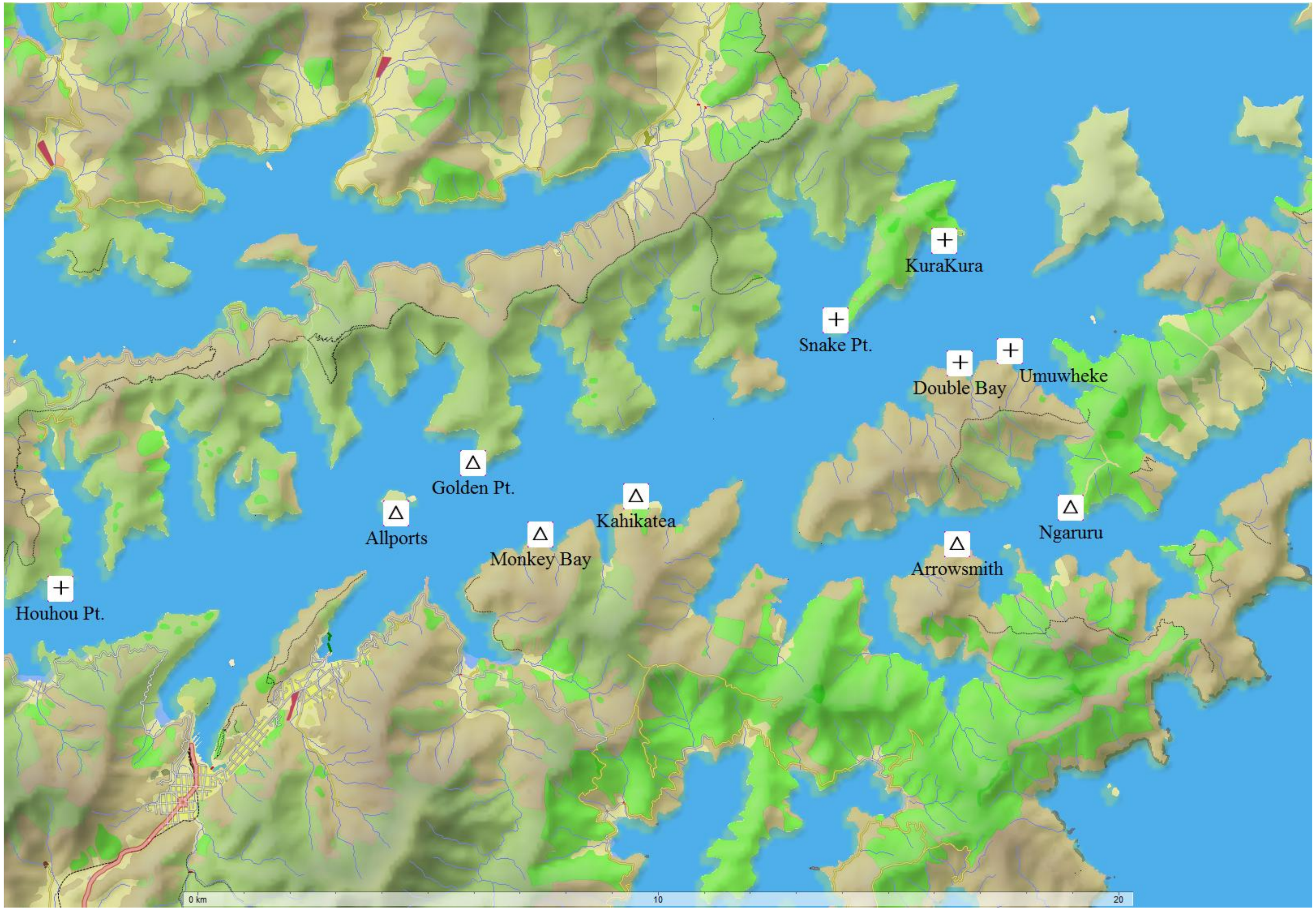

Figure 5. Location of subtidal bedrock sample sites. Control = crosses, impact = triangles.

4.0 Results

4.1 Intertidal cobble-small boulder

4.1.1 Macroinvertebrate species (intertidal cobble-boulder)

For control sites, mean number of invertebrate species living on and under rocks ranged from 5 to 12 (mid tide) and 7 to 12 species (low tide) over the 5324 day study (Figures 6 and 7). Occasionally, a mean value breached these ranges (e.g. May 2001 at the low tide level). No change to the mean number of invertebrates at mid or low tide control sites occurred following the Bylaw.

At impact sites, the mean number of species at both tidal levels ranged between 0 and 8 species (Figures 6 and 7). Three of the four impact sites exhibited an increase following the Bylaw. Prior to the Bylaw, Deep Bay consistently supported the most species of the four impact sites. After the Bylaw, the mean number of species recorded at Deep Bay and two other impact sites increased reaching levels recorded at control sites in particular years.

At both tidal heights, the mean number of species from pooled control sites was consistently higher compared to the pooled impact treatment (Figures 6 and 7). The mean number of species reached its lowest point in February 2000 prior to the Bylaw. Following the speed restriction, the pooled mean number of species at impact sites increased relative to control sites. At the end of the study, the pooled impact values reached their highest level since the start of the study but levels remained below the control treatment.

4.1.2 Mollusc density (intertidal cobble-boulder)

The mean density of intertidal molluscs ranged from 15 to 45 individuals per rock at mid tide and 10 to 40 individuals per rock at low tide (Figures 8 and 9). Occasional mean values for control sites breached these ranges (e.g. Blumine south at low tide, 1995). No obvious change to individual control site values occurred in relation to the navigational bylaw.

At impact sites, the mean density of molluscs at mid and low tide was lower than at control sites (Figures 8 and 9). Prior to the 18 knot speed restriction, the Deep Bay impact site consistently supported the highest density of molluscs. The remaining impact sites supported very low densities or, at times, no molluscs. Apart from Picton Point, the density of molluscs increased at both tidal heights after the navigational bylaw (Figures 8 and 9).

The scale of this increase was relatively modest and variable between sites, with the greatest increase recorded at Deep Bay.

The mean density of mid tide molluscs from the pooled control treatment remained higher than the pooled impact treatment over the duration of the study (Figure 8). Mid tide mollusc densities increased following the introduction of the Bylaw, peaking in February 2005 and remaining well below densities recorded at the pooled control treatment.

Similarly, the low tide pooled impact value increased after the Bylaw, peaking in February 2005 before declining between February 2006 to 2010 (Figure 9). The impact treatment value came close to particular lower values recorded for the pooled control treatment (i.e. May 1997, December 2002, and February 2010) (Figure 9).

4.1.3 Cast invertebrates (intertidal cobble-boulder)

The number of species washed ashore at control sites varied little over the duration of the study (0-2 species) (Figure 10). On three occasions, 3-4 species were recorded at control sites. After February 2005, a low number of cast species were recorded at impact sites. Prior to 2005, 3-5 species of cast animals were regularly recorded and a peak of 11 species occurred at Dieffenbach in January 1996. Pooled values showed a similar pattern with the control treatment remaining relatively low for the study duration. The impact treatment showed a greater variation and higher values particularly in January 1996, 1997, February 2000 and December 2002 compared to controls (Figure 10).

The density of cast animal species recorded for both control and impact sites remained relatively low for most of the study (Figure 11). Dieffenbach was the exception, with a peak of invertebrate density in January 1996. For the pooled control treatment, the mean density of species remained relatively low both before and after the Bylaw, compared to the impact treatment where elevated densities were recorded before and on three occasions after the speed restriction (Figure 11).

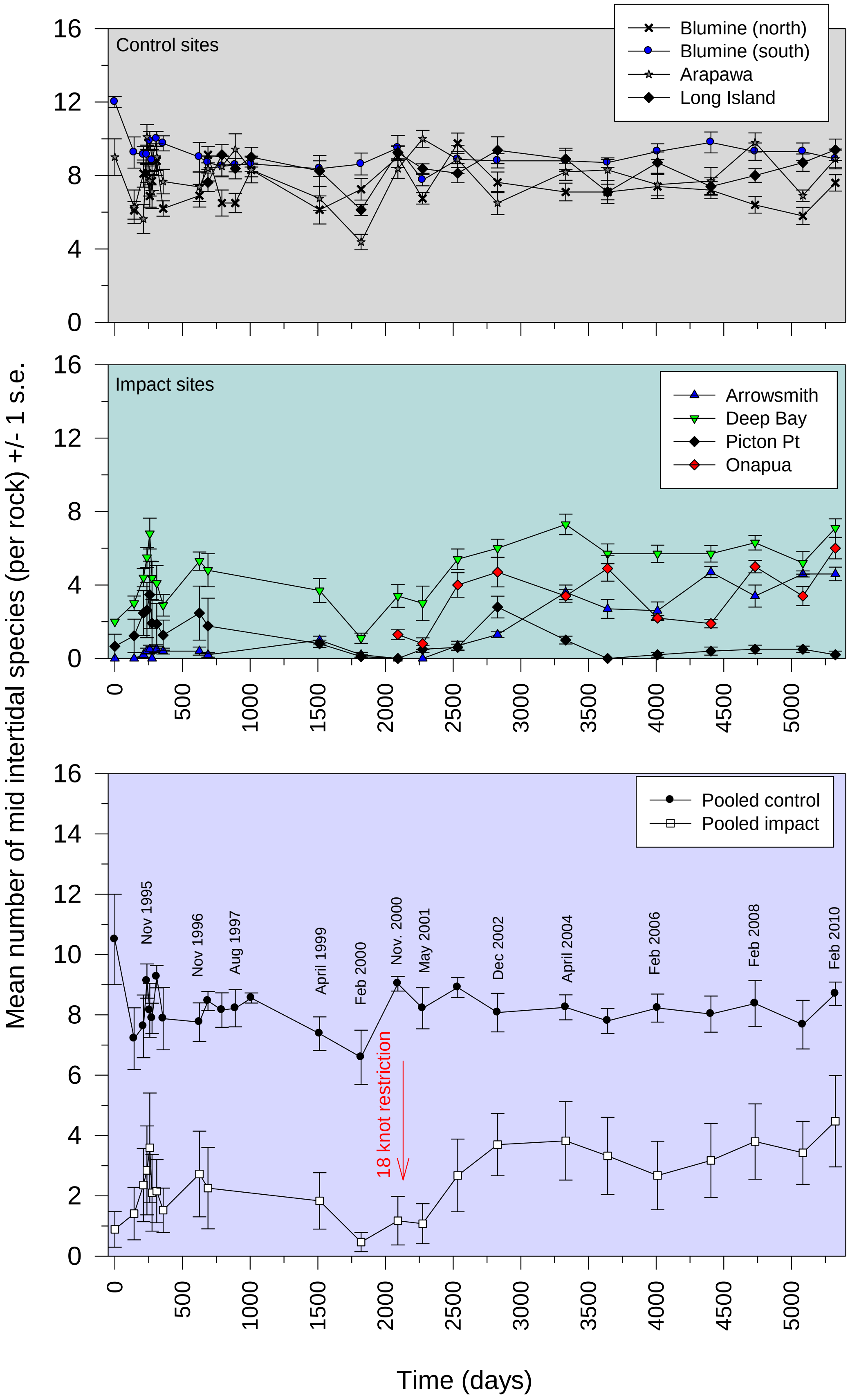

Figure 6. Mean number of invertebrate species recorded from mid tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to February 2010).

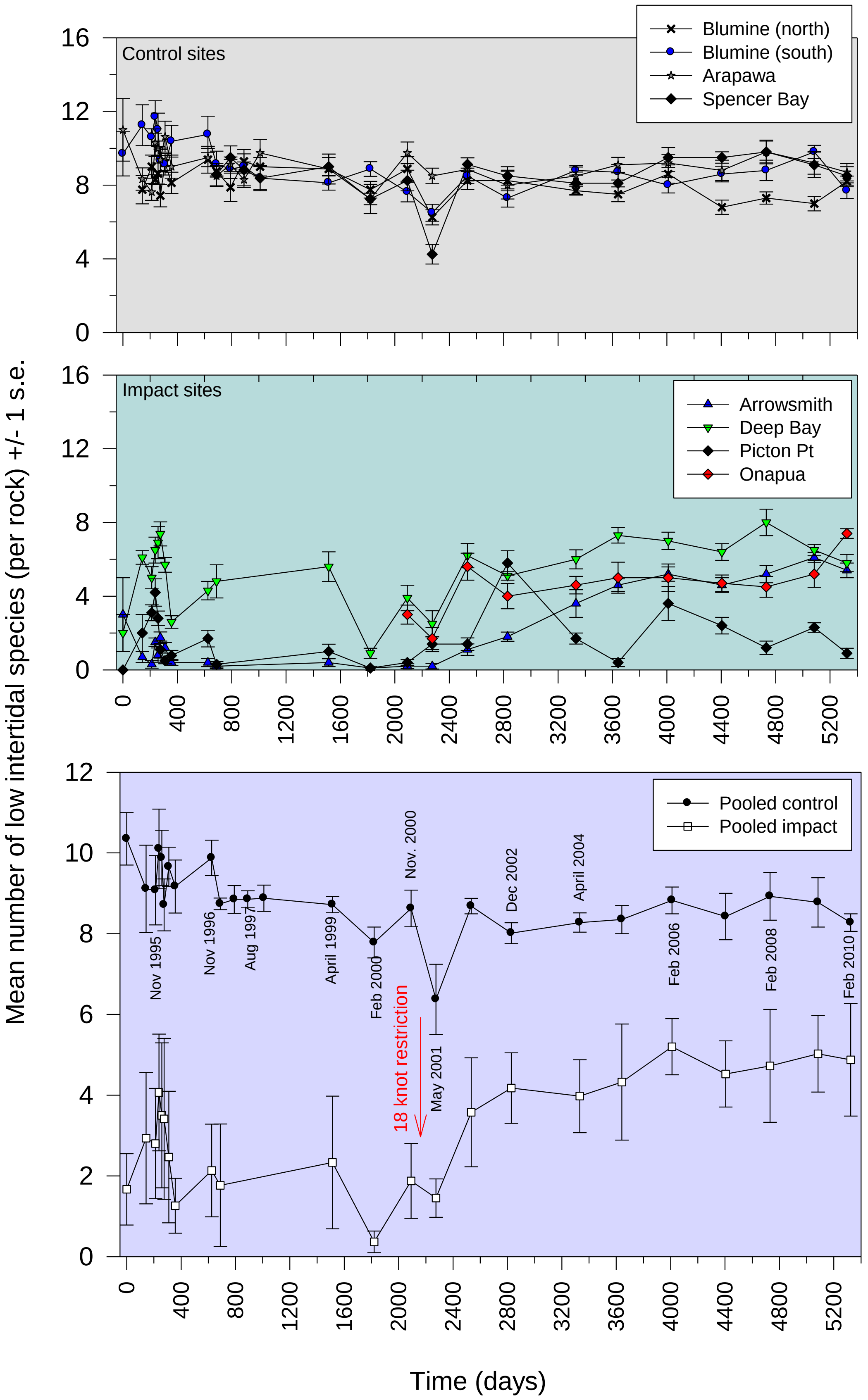

Figure 7. Mean number of invertebrate species recorded from low tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to February 2010).

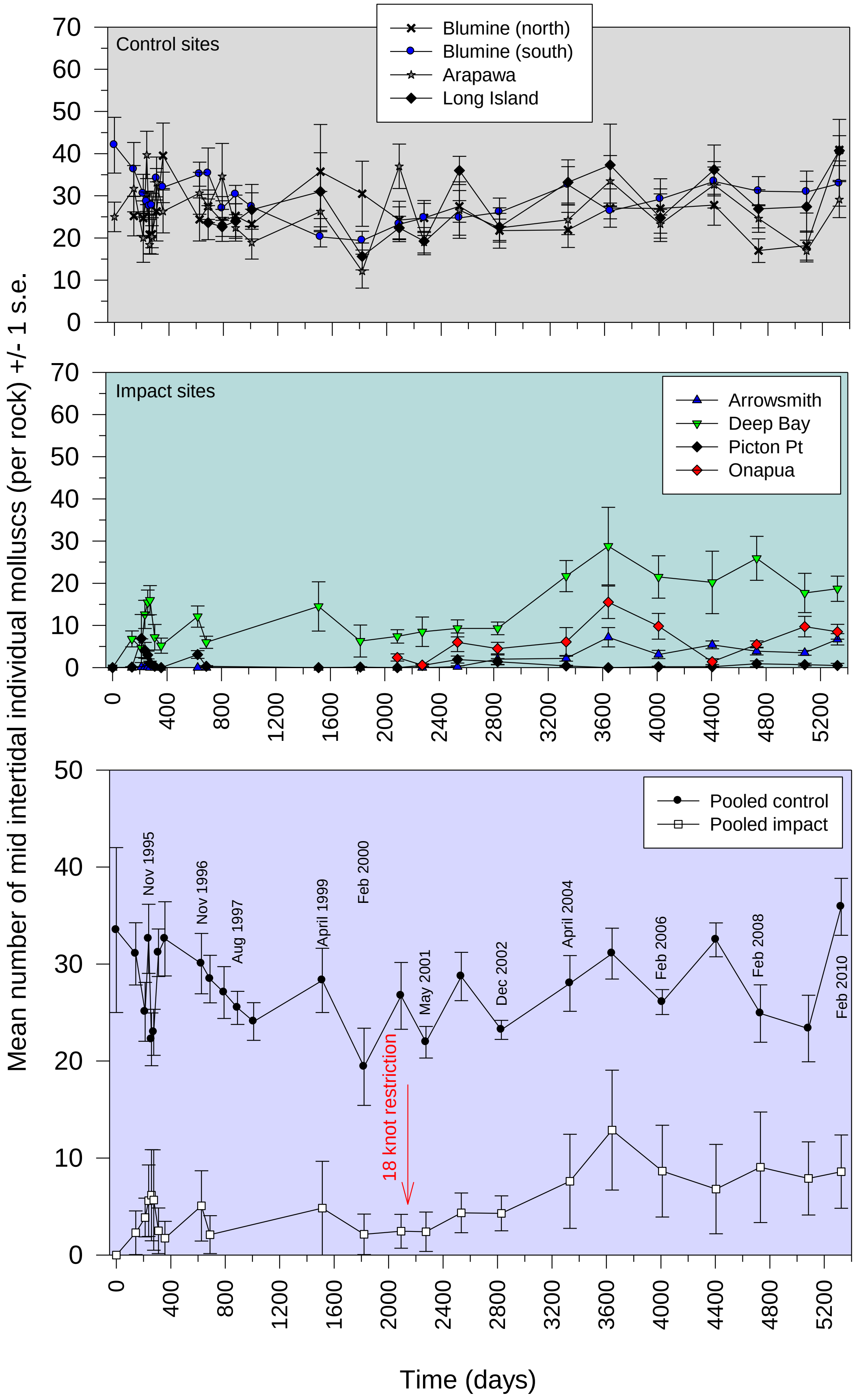

Figure 8. Mean density of individual molluscs recorded from mid tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to February 2010).

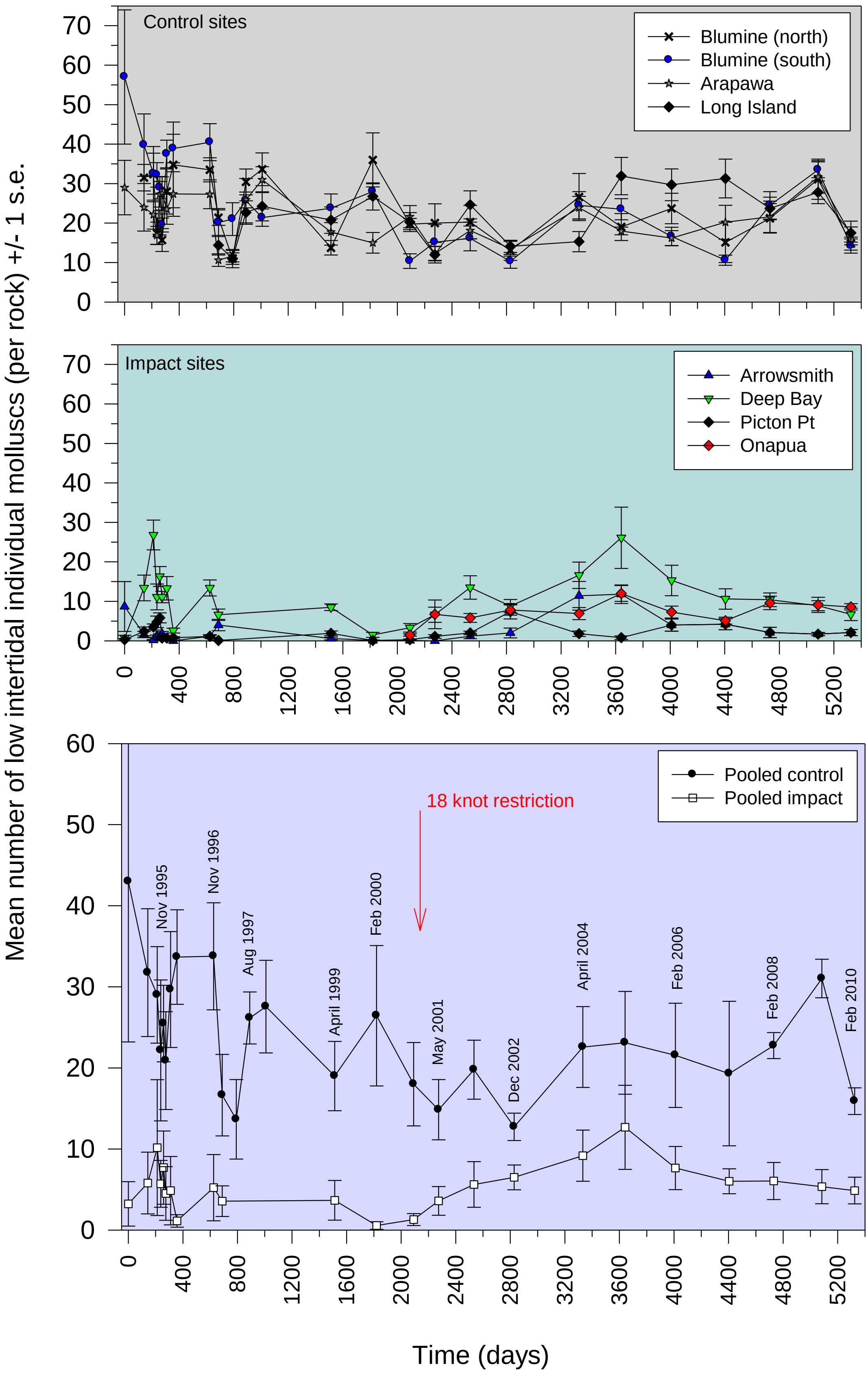

Figure 9. Mean density of individual molluscs recorded from low tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to February 2010).

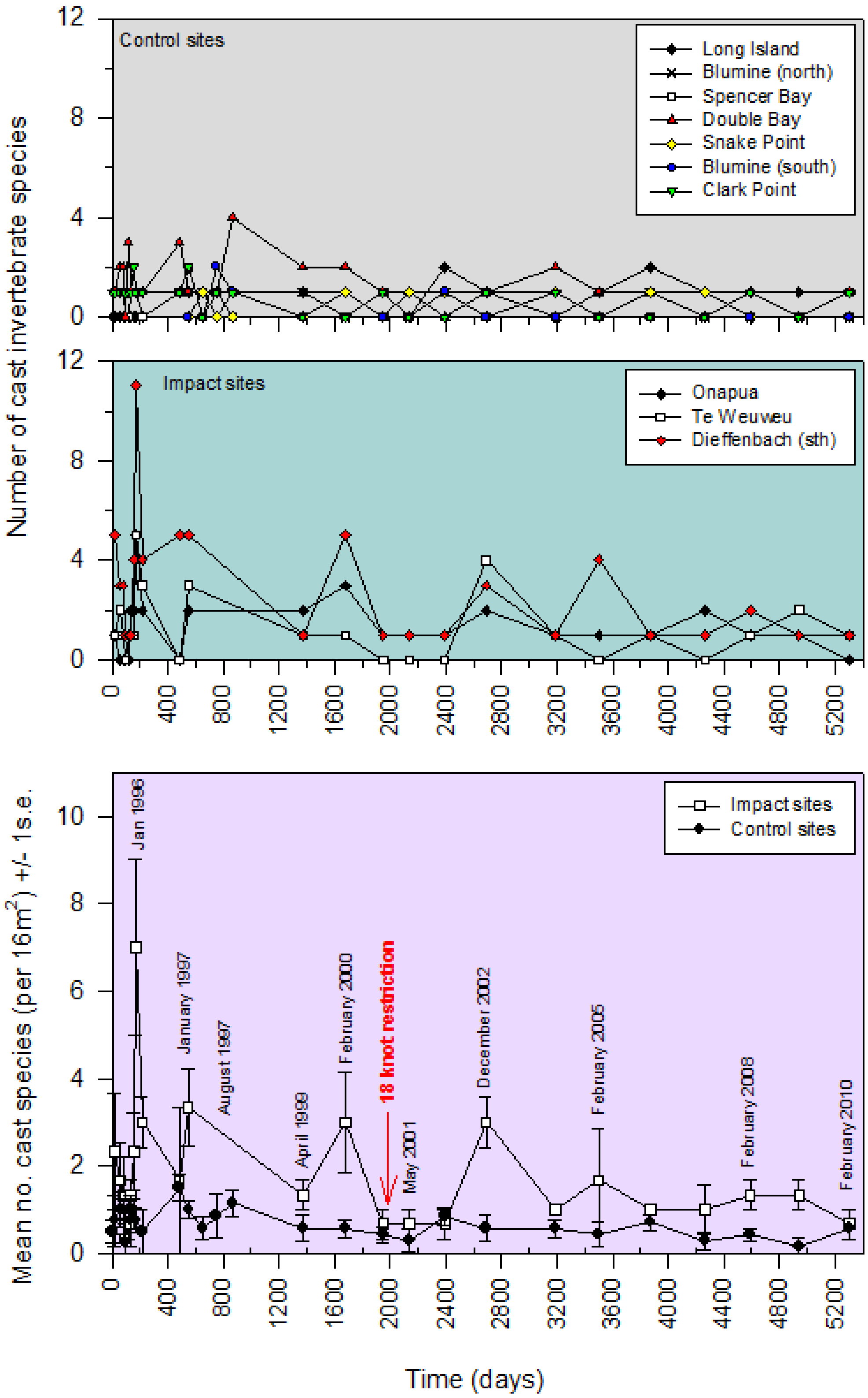

Figure 10. Number of species recorded from cast animal quadrats sampled at control and impact sites and from mean pooled treatments from November 2000 to February 2010.

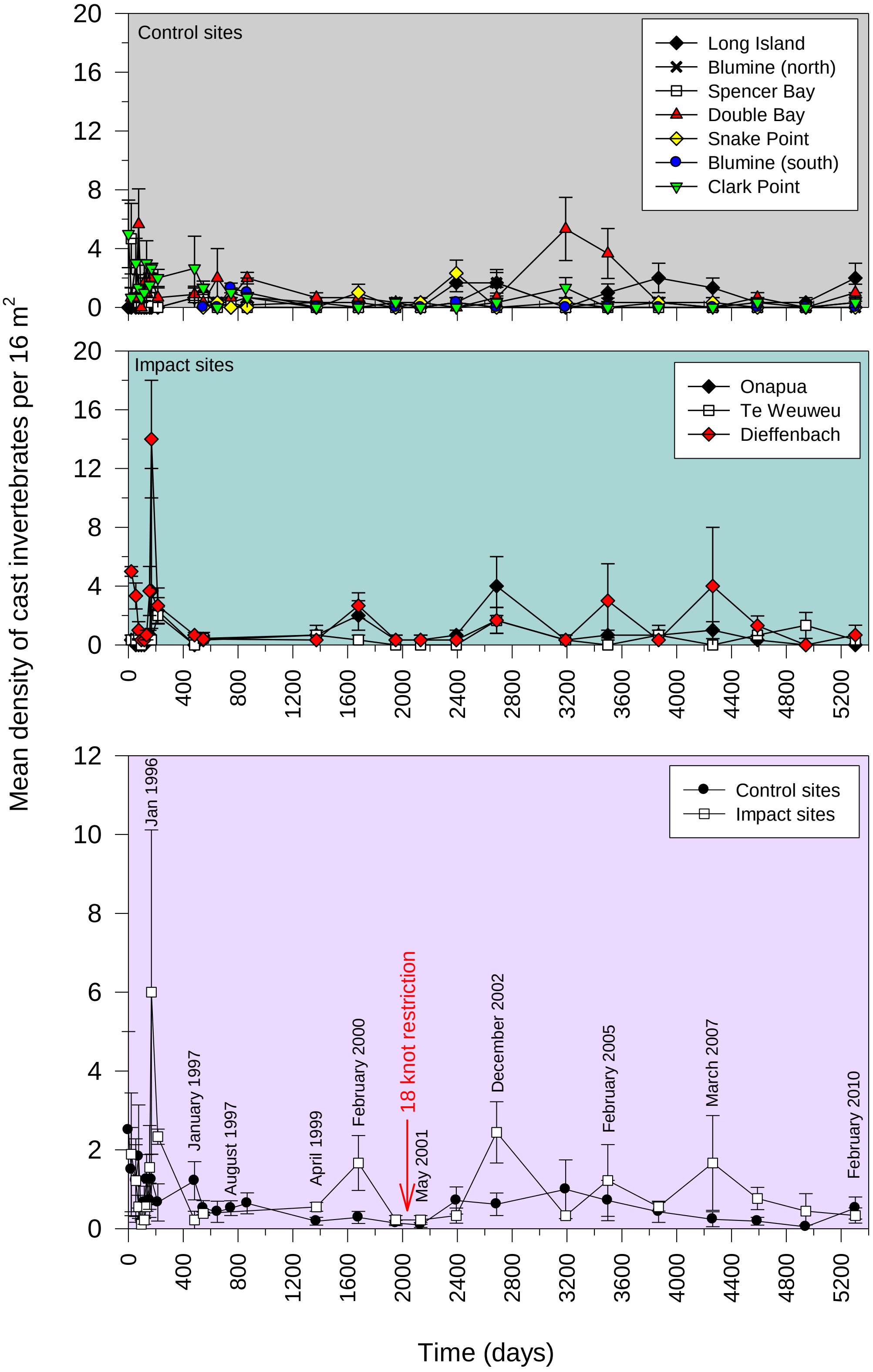

Figure 11. Mean density of species recorded from cast animal quadrats sampled at pooled control and impact sites from November 2000 to February 2010.

4.2 Subtidal cobble-small boulder

4.2.1 Kina (subtidal cobble-boulder)

Kina (*Evechinus chloroticus*) density varied dramatically between control sites with two of the five sites regularly supporting higher numbers (i.e. Long Island and Clark Point) (Figure 12). Kina densities ranged from 0.5 to 9 individuals per m^2. Despite the relatively large between site variability, densities at individual sites often remained relatively consistent over the duration of the study. No obvious consistent increase or decrease occurred in relation to the Bylaw.

Prior to the Bylaw, kina were always most abundant at Dieffenbach with relatively low numbers counted at the four remaining impact sites. Following the Bylaw, kina densities increased dramatically at two of the five impact sites (i.e. Onapua and Monkey Bay) (Figure 12). The density of kina at Dieffenbach remained at comparable levels before and after the speed restriction.

The high variability recorded between the five control sites resulted in relatively large error bars associated with pooled means (Figure 12). Kina density for the control treatment also fluctuated throughout the study, with peaks in 1995, February 2002, April 2004, February 2006 and March 2007. Lowest values (<2.5 individuals per m^2) for the control treatment were recorded in December 2002 and February 2009 (Figure 12). In contrast, kina densities at the impact treatment initially declined from 1995 and 1996 to a low in November 2000. Over this early period, the impact density was well below the pooled control treatment value. Following the Bylaw, the impact treatment increased to levels above the lower control treatment levels (Figure 12). Kina densities at the impact treatment peaked between April 2004 and February 2006. A decline also occurred at the control treatment over this period.

4.2.2 Cats-eye snail (subtidal cobble-small boulder)

At control sites, the mean cats-eye density (*Turbo smaragdus*) remained relatively consistent throughout the study with means ranging from 0 to 11 individuals per m^2 (Figure 13). Densities were consistently lowest from the eastern-most control sites located at Long Island and Clark Point.

At impact sites, densities varied both within and between sites over the study (Figure 13). Highest densities were recorded in the first year of the study followed by a period where all impact sites showed declining cats-eye densities. Following the Bylaw, the abundance of snails increased at four of the five impact sites.

Cats-eye densities from the pooled control subtidal cobble-small boulder treatment remained relatively consistent, with small lows recorded in November 1995, 1996 and May 2001 (Figure 13). In contrast, the pooled impact cats-eye density declined from approximately 7.5 to 17 individuals per m^2 in 1995 and 1996 to <3 individuals per m^2 in March 2000 to May 2001. Following the Bylaw, the pooled impact mean increased above the control treatment where it remained to the end of the study (Figure 13). No change to the control treatment density of cats-eye snails was recorded in relation to the Bylaw.

4.2.3 Black-foot paua (subtidal cobble-small boulder)

Black-foot paua (*Haliotis iris*) were always present at Clark Point, but were absent or uncommon at the four other control sites (Figure 14). At Clark Point, paua density varied from 0 to 1.6 individuals per m^2. Black-foot paua at Clark Point were usually in <1 m depth.

At impact sites, paua density remained low, but paua were recorded from three of the five sites reaching densities of 0.25 individuals per m^2. Highest densities of paua were recorded at Te Weuweu Bay and Arrowsmith (Figure 14). No change to the density of black-foot paua occurred at control or impact sites following the Bylaw.

The pooled density of paua for the control treatment reflected the pattern in abundance recorded from Clark Point. For the impact treatment, the greatest variation in paua density occurred in the first 800 days of the study followed by a stable period of low paua density (i.e. August 1997 to February 2010) (Figure 14).

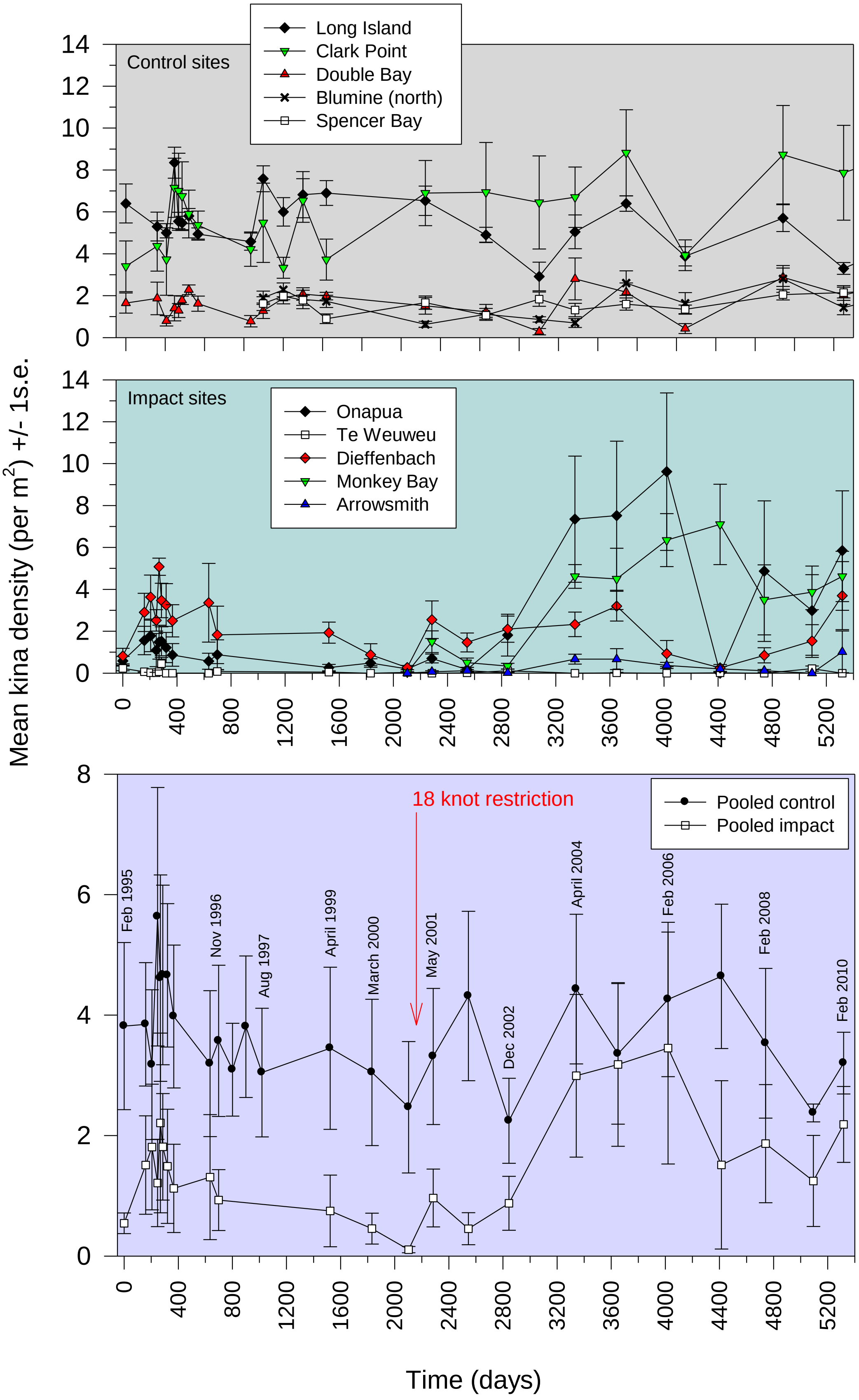

Figure 12. Mean density of kina recorded from shallow subtidal cobbles and small boulders in Queen Charlotte Sound and Tory Channel from March 1995 to February 2010.

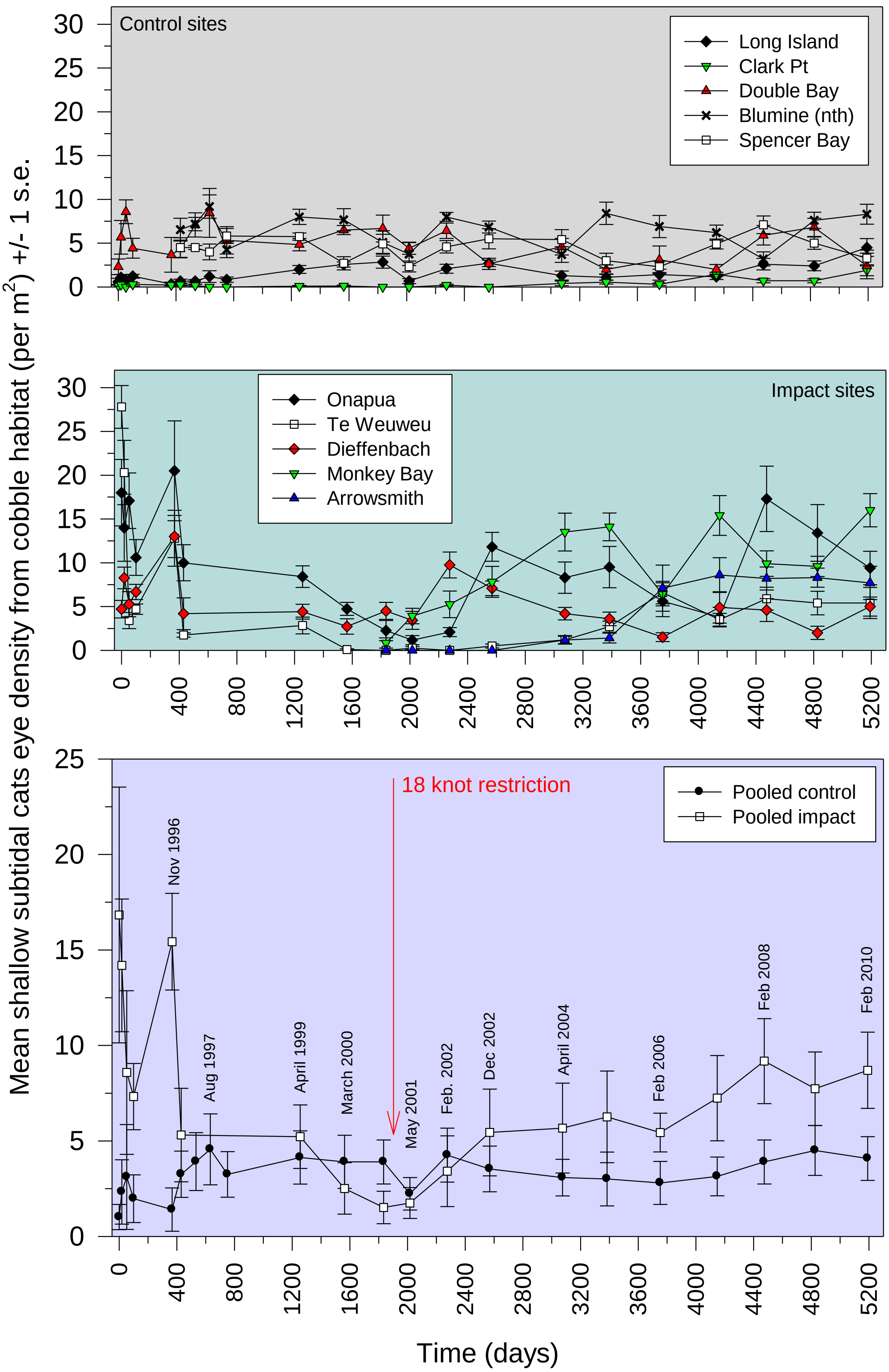

Figure 13. Mean density of cats-eye snails recorded from shallow subtidal cobbles and boulders in Queen Charlotte Sound and Tory Channel from March 1995 to February 2010.

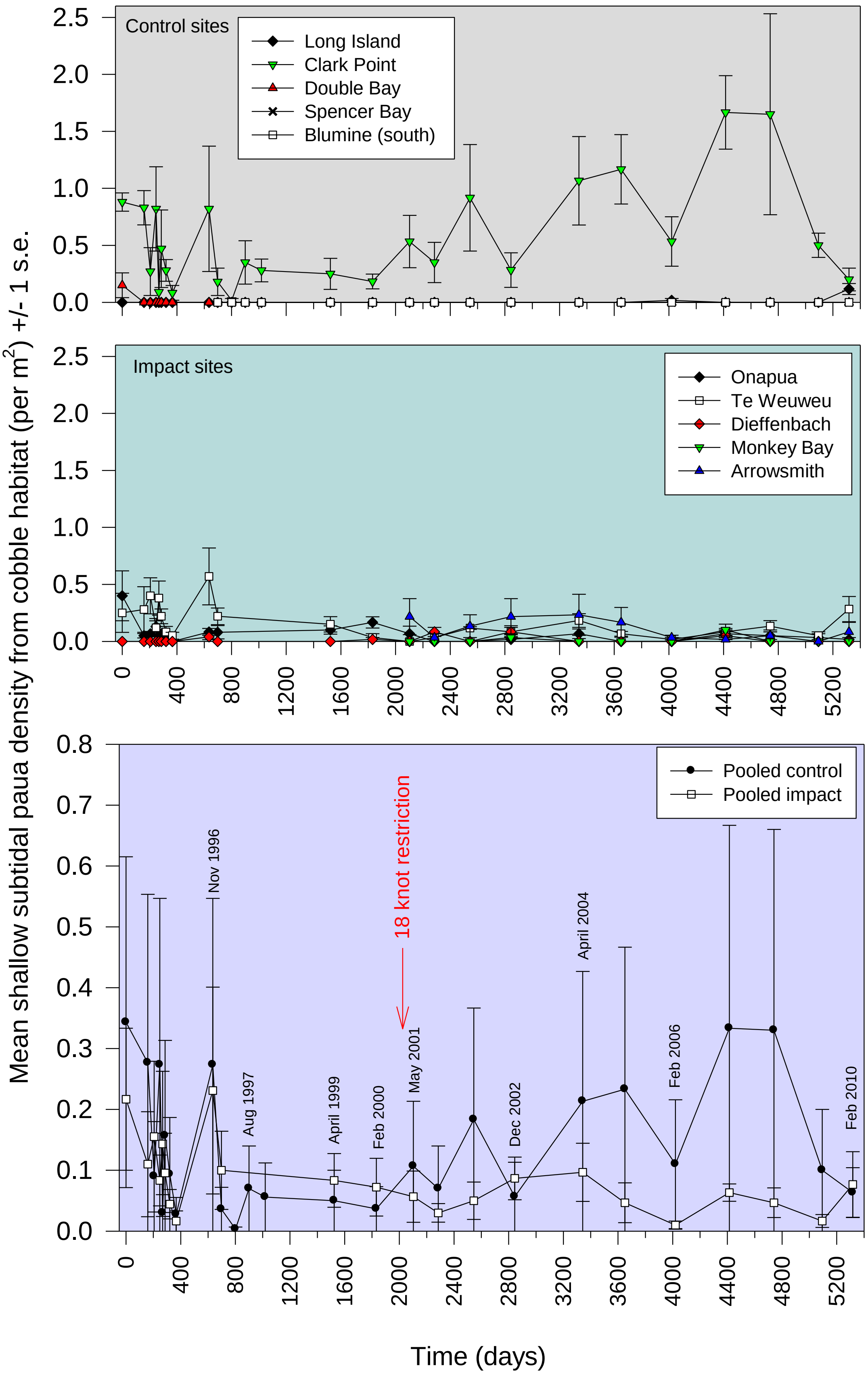

Figure 14. Mean density of black-foot paua recorded from shallow subtidal cobbles and boulders in Queen Charlotte Sound and Tory Channel (March 1995 to February 2010).

4.3 Intertidal bedrock

4.3.1 Mobile molluscs (intertidal bedrock)

The number of detachable or "mobile" mollusc species on intertidal bedrock control sites ranged from 4 to 8 compared to 1 to 7 at impact sites (Figure 15). Both steep gradient shores (i.e. Tory Channel and Ngaruru) supported the lowest number of species (1 to 5) for any site in the present study. The number of species recorded from the two steep gradient control sites supported 5 to 8 species.

The pooled number of control intertidal bedrock species remained higher than the impact treatment throughout the study. Following February 2005, however, the difference between the two treatments reduced compared to levels recorded in the first four years of the study (Figure 15). This reduction was primarily due to a decline in the mean number of species at control sites rather than an increase at impact sites. In February 2010, the mean number of species at the impact treatment declined to an all time low for the study.

The density of mobile molluscs at control sites ranged from 6.8 to 92.2 individuals per m^2, while 0.1 to 39.3 individuals per m^2 were counted at impact sites (Figure 16). At Double Bay and Snake Point, the density of mobile molluscs fluctuated whereas mollusc densities remained relatively stable at other control sites. Umuwheke always supported highest densities and Blumine (south), Houhou Point and Kurakura Point supported lowest densities. At impact sites, the abundance of mobile molluscs increased at some sites and remained relatively low at others (Figure 16). Impacts sites at Monkey Bay, Kahikatea, and Golden Point supported densities comparable to low density control sites, while Tory and Ngaruru supported none or few molluscs throughout the study.

Mobile mollusc densities from the pooled control treatment remained above the impact treatment throughout the study. Despite low densities recorded at Ngaruru and Tory Channel sites, the mean density of mobile molluscs steadily increased after the Bylaw at the pooled impact treatment, peaking in February 2006 (Figure 16). Since this time, the density of mobile molluscs from the impact treatment has fallen back, but remains above levels observed at the start of the study.

4.3.2 Cats-eye snail (intertidal bedrock)

At control sites (Umuwheke, Houhou Point and Double Bay), cats-eye density was highly variable ranging from near zero to 10, and sometimes 20, individuals per m^2. At most impact sites, densities were even more variable ranging from 0 up to 30 individuals per m^2 (Figure 17).

Cats-eye densities increased dramatically for the pooled impact treatment following the Bylaw and April 2004. The 2004 peak was followed by a decline to March 2008 when densities returned to levels recorded at the start of the study (Figure 17). At the end of the study, their density increased to densities comparable to the control treatment. The control treatment, however, also exhibited variation with densities crashing to a low in February 2006.

4.3.3 Topshell (intertidal bedrock)

The mean density of topshell (*M. aethiops*) from intertidal bedrock control sites ranged from 1.1 to 67.7 individuals per m^2. Topshell abundance was highest from north-facing sites (i.e. Snake Point, Umuwheke and Double Bay) compared to south-facing sites (i.e. Blumine south, Houhou and Kurakura). At low density sites, the abundance of topshells remained relatively constant, compared to high density sites where their abundance was variable with peaks and troughs (Figure 18).

Mean topshell density at impact sites ranged from 0 to 20 individuals per m^2. Apart from a small increase in February 2005 at Kahikatea and in February 2006 at Ruaomoko, the density of topshells remained low at most impact sites over the duration of the study.

Pooled mean topshell density was always highest at the control treatment compared to the impact treatment (Figure 18). An increase in the abundance of topshells occurred after the Bylaw, peaking in February 2006 and followed by a decline to levels comparable to the start of the study. In the pooled control treatment, densities also increased after the Bylaw with peaks in December 2002 and February 2006 followed by a decline to a low in February 2009. At the end of the study, the abundance of topshell at the pooled control treatment returned to levels close to those recorded at the start of the study (Figure 18).

4.3.4 Oyster borer (intertidal bedrock)

The abundance of oyster borer (*L. scobina*) ranged from 0 to approximately 45 individuals per m^2 at control sites compared to 0 to 20 individuals per m^2 at impact sites. At control sites, apart from Umuwheke and Double Bay, the density of oyster borer remained relatively consistent ranging from 0 to 14 individuals per m^2 (Figure 19). Their abundance varied at Umuwheke and Double Bay over the duration of the study.

At the start of the study, oyster borer density at impact sites was low compared to most control sites. Their abundance increased at Golden Point, Kahikatea and Monkey Bay, peaking between February 2005 and March 2008, then declining to levels above the start of the study (Figure 19).

Oyster borer snails were always more abundant in the pooled control treatment compared to the impact treatment. This was due to the high numbers of snails at Umuwheke and, at particular periods, Double Bay. The pooled mean density of oyster borer for both treatments started low and initially increased after the introduction of the Bylaw with highest values recorded at the control treatment between February 2007 and 2009 and at the impact treatment between February 2006 and March 2008.

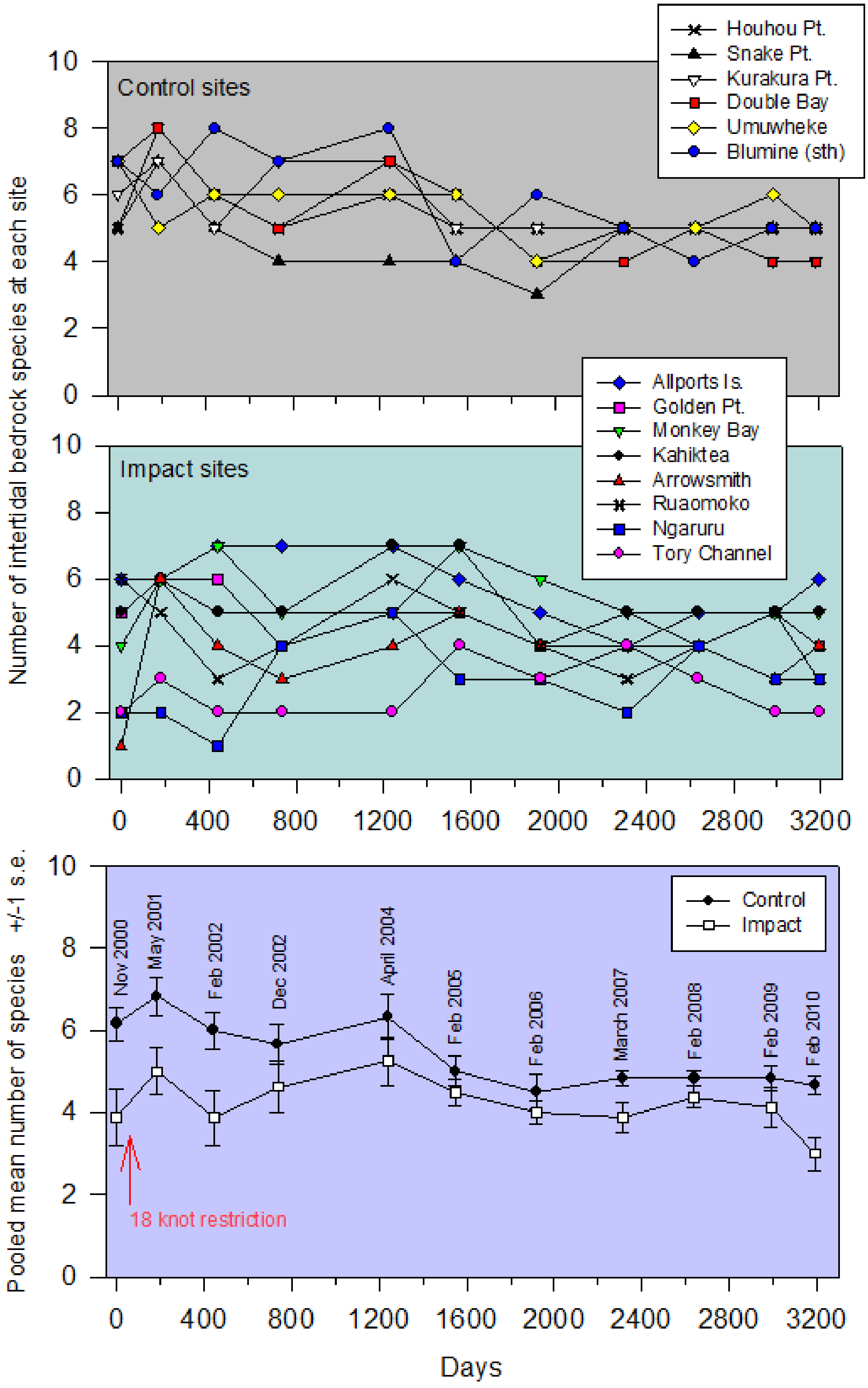

Figure 15. Number of mobile mollusc species at intertidal bedrock control and impact sites from November 2000 to February 2010.

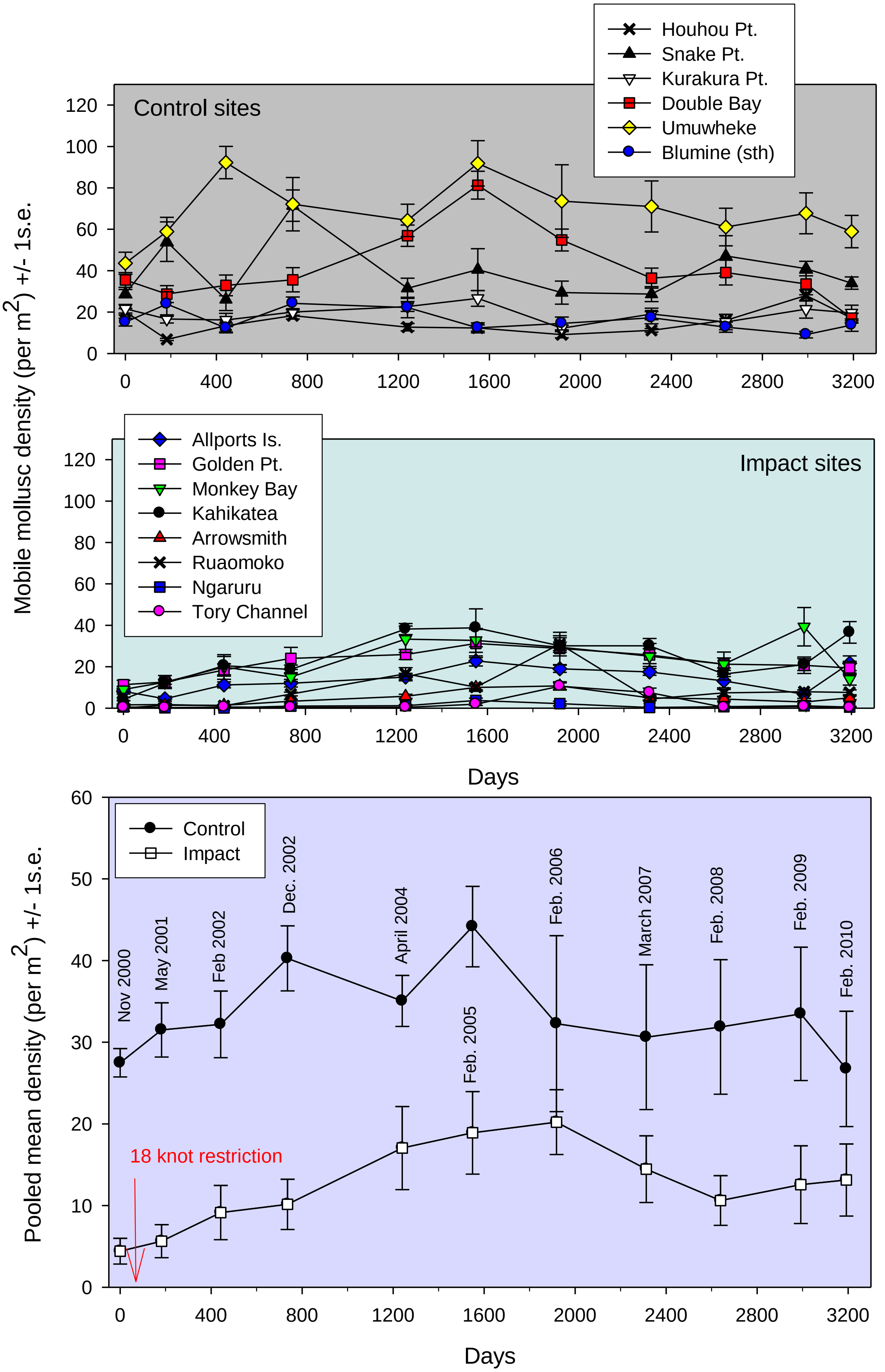

Figure 16. Density of mobile molluscs at intertidal bedrock control and impact sites from November 2000 to February 2010.

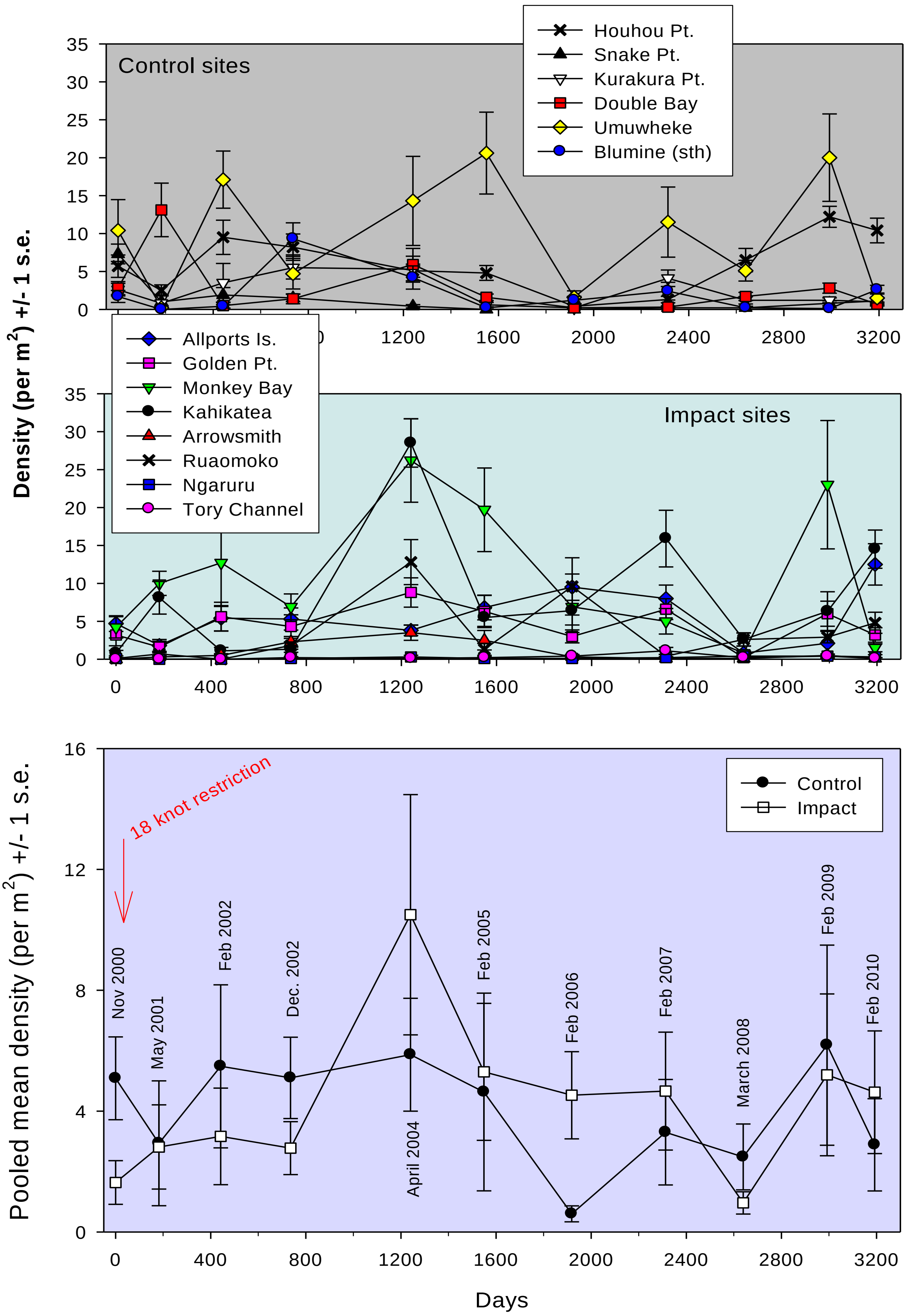

Figure 17. Mean density of cats-eye snail (*Turbo smaragdus*) from intertidal bedrock control and impact sites and pooled treatments from November 2000 to February 2010.

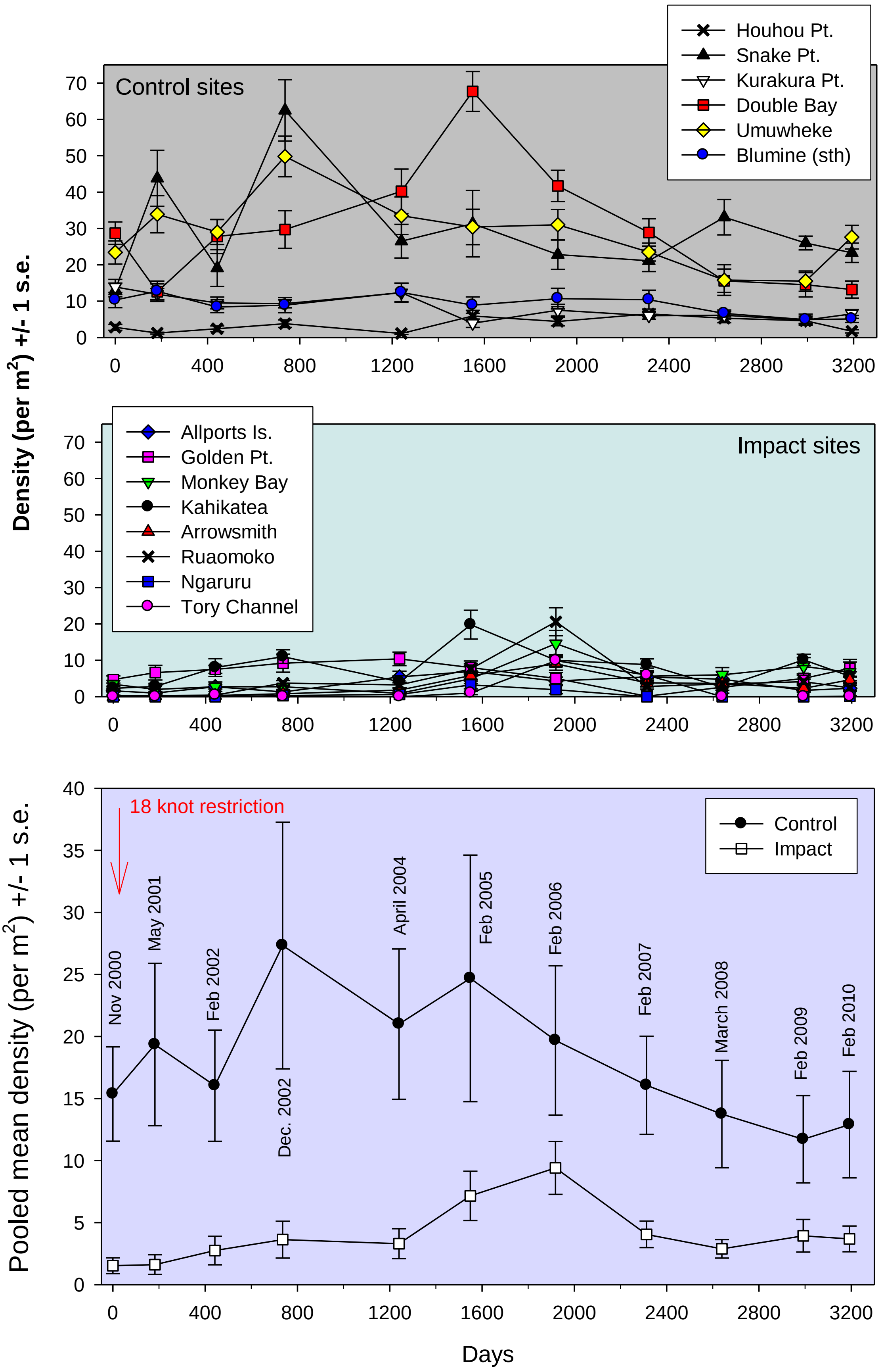

Figure 18. Mean density of topshell (*Melagraphia aethiops*) from intertidal bedrock control and impact sites and pooled treatments from November 2000 to February 2010.

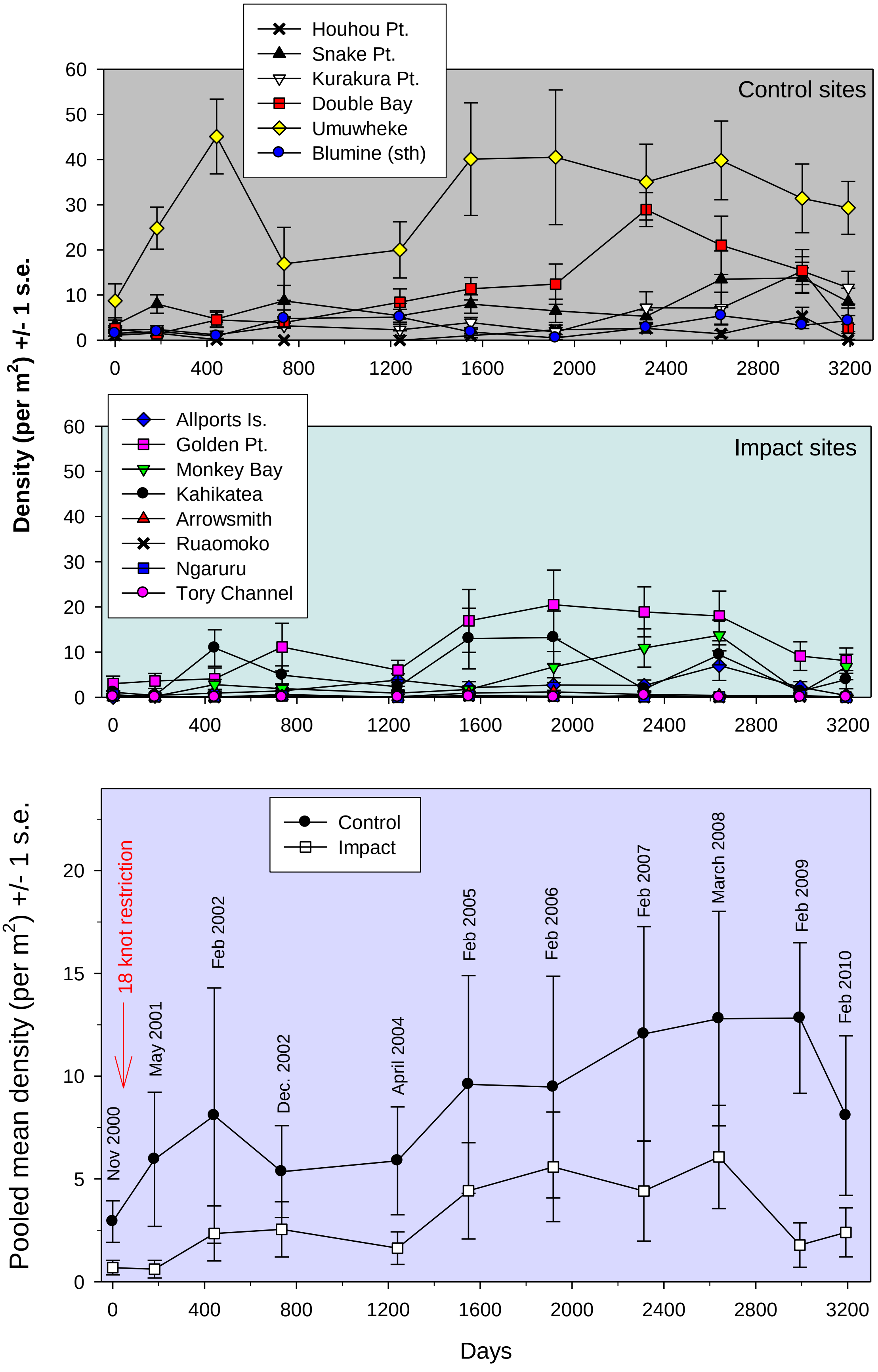

Figure 19. Mean density of oyster borer (*Lepsiella scobina*) from intertidal bedrock control and impact sites and pooled treatments from November 2000 to February 2010.

4.4 Subtidal bedrock (0-0.5 m depth)

4.4.1 Macroinvertebrates (subtidal bedrock 0-0.5 m)

The number of shallow subtidal bedrock invertebrate species from control sites ranged from 7 to 13 species compared to 1 to 14 species at impact sites (Figure 20). The number of species increased at Snake Point over the duration of the study, while at other control sites the number of species remained relatively stable. Lowest numbers of species were recorded at impact sites prior to the Bylaw with species number increasing above these initial low levels for the reminder of the study (Figure 20).

The mean number of species from the pooled control treatment ranged from 8.2 to 10.6 per m^2 over the duration of the study with lows in November 2000 and February 2006 (Figure 20). In contrast, the pooled impact mean started at an all time low of 4 species per m^2 and increased to a peak of 9.2 species per m^2 in February 2006. This peak was above the value recorded for the control treatment in that year. After this peak, the mean number of species for the pooled impact treatment declined over four consecutive years reducing it to levels above the start of the study but well below the 2006 peak (Figure 20).

The density of invertebrate species at shallow subtidal bedrock control sites ranged from 6.2 to 44.8 individuals per m^2 compared to 0.8 to 85 per m^2 for impact sites (Figure 21). At control sites, densities remained relatively stable. Densities at Umuwheke Bay for example was consistently the highest of all control sites, followed by Double Bay and Snake Point. Houhou Point consistently supported the lowest density of shallow subtidal bedrock species. For impact sites, Arrowsmith and Ngaruru consistently supported the lowest density of shallow subtidal species with both sites showing little change after the Bylaw (Figure 21).

Pooled control treatment density values were variable throughout the study, with lows in November 2000, February 2006 and 2009 and highs in April 2004, February 2007 and 2010 (Figure 21). These highs and lows were augmented as these occurrences often coincided at many of the individual sites each year. For the impact treatment, lowest values were recorded in the first four years of the study starting in November 2000, representing the lowest value for the study. Mean impact densities increased above the control treatment in February 2006 and maintained comparable densities until 2010 when densities again dropped below the control level (Figure 21).

4.4.2 Kina (subtidal bedrock 0-0.5 m)

The abundance of kina ranged from 0 to 20.5 individuals per m^2 at control sites compared to 0 to 36.9 individuals per m^2 at impact sites. At control sites, kina density remained relatively stable over the duration of the study with greatest fluctuations occurring at Umuwheke (Figure 22). The density of kina was consistently lowest from Houhou Point where individuals were relatively rare. At impact sites Ngaruru and Arrowsmith, located in Tory Channel, kina were also absent or rare (Figure 22). At all other impact sites, kina density generally increased from low values at the start and peaked many times throughout the study.

Prior to the Bylaw, the mean kina density at the pooled impact treatment was below the control treatment level (Figure 22). For the next three sample occasions (May 2001, February 2002, December 2002), pooled mean kina densities were comparable with the control treatment. In April 2004, kina density at the impact treatment increased well above densities recorded from the control treatment (Figure 22). The pooled control mean density of kina also increased above initial levels recorded since the start of the study. The scale of the increase at the control treatment was, however, smaller than the increase recorded for the impact treatment (Figure 22).

4.4.3 Cats-eye snail (subtidal bedrock 0-0.5 m)

At control sites, cats-eye density ranged from 2.2 to 23.5 snails per m^2 compared to 0 to 45.4 individuals per m^2 at impact sites. At control sites, cats-eye density remained relatively stable over the duration of the study with only modest increases and decreases between sample events (Figure 23). Their density was consistently lowest from Houhou Point and Kurakura and highest from Umuwheke, Double Bay and Snake Point. Lowest numbers of cats-eye were recorded from impact sites located in Tory Channel (i.e. Ngaruru and Arrowsmith) (Figure 23). At all other impact sites, their density increased from early lows to dramatically higher densities from December 2002 onwards. A large decrease in the number of snails occurred at four of the six impact sites in February 2010.

The density of cats-eye from the pooled control treatment increased slightly over the duration of the study with peaks occurring in May 2001, February 2007 and February 2010. The snail density at the pooled impact treatment increased consistently over the duration of the study to a high in February 2009 when it dropped back to the control level in 2010 (i.e. from 18.3 to 11.3 snails per m^2) (Figure 23).

4.4.4 Black-foot paua (subtidal bedrock 0-0.5 m)

Black-foot paua were recorded from three of the five subtidal bedrock control sites and five of the six impact sites over the duration of the study. Their density was low but variable, ranging from 0 to 0.3 individuals per m^2 at controls and 0 to 0.5 individuals per m^2 at impact sites. For the pooled control treatment, mean density remained low with no individuals recorded in four of the 11 sample occasions (Figure 24). Their density at the pooled impact treatment was more variable than the control treatment, but densities remained low.

4.4.5 11 arm seastar, kina and sea cucumber (subtidal bedrock 0-0.5 m)

Individual site data for 11 arm seastar, kina and sea cucumber collected from 20 x 1 m^2 quadrats were pooled for each treatment (Figure 25). Apart from 2010, the density of 11 arm seastar (*Coscinasterias muricata*) was consistently higher from the pooled impact treatment compared to the control treatment. Their density increase for the control treatment was due to a population boom at one site (i.e. Houhou Point).

Kina (*E. chloroticus*) density from the pooled impact and control treatments both increased over the duration of the study. The scale of the increase was greatest from the pooled impact treatment (Figure 25). Impact densities peaked in February 2006 and declined below control levels for the first time since February 2002 in February 2010.

In November 2000 and February 2010, the density of sea cucumbers at the pooled control treatment increased above impact levels. Apart from these occasions, sea cucumber densities were very low at both the impact and control treatments (Figure 25). No increasing or decreasing trends were apparent over the duration of the study.

4.5 Subtidal bedrock (1.5-2 m depth)

4.5.1 Macroinvertebrates (subtidal bedrock 1.5-2 m)

Between 6 and 14 species of invertebrate were recorded at deep bedrock control sites compared to 2 to 11 species at impact sites. No dramatic increase or decrease was recorded from either treatment over the duration of the study (Figure 26). The mean number of species remained higher at control sites for all of the study but the scale of this difference was relatively low compared to differences recorded at shallow strata (Figures 20 and 26).

The density of invertebrates recorded from deep bedrock control and impact sites were comparable (Figure 27). Houhou Point control site and Ngaruru and Arrowsmith impact sites consistently supported the lowest densities of invertebrates (10-45 individuals per m^2). A decline in the abundance of invertebrates was recorded in February 2010, however this occurred at a number of impact and control sites.

The pooled data showed similar trends for both impact and control treatments with mean values crossing on two occasions (Figure 27). Peaks and troughs were recorded for both treatments at comparable levels between treatments.

4.5.2 Kina (subtidal bedrock 1.5-2 m)

The abundance of kina ranged from 0 to 10.9 individuals per m^2 at control sites compared to 0 to 13.1 per m^2 at impact sites. At control sites, abundance was variable with density peaking at many sites on two occasions (Figure 28). Kina density was consistently lowest at Houhou Point and highest from Umuwheke, Kurakura and Double Bay. At Ngaruru and Arrowsmith impact sites, kina were absent or rare (Figure 28). At all other impact sites, kina density generally increased over the duration of the study peaking in December 2002, February 2005, March 2008 and February 2009.

For the pooled impact and control treatments, the density of kina followed a comparable upward trend throughout the study (Figure 28). Pooled mean kina density for the impact treatment increased above control values on two occasions, however, error bars overlapped on all sample occasions.

4.5.2 Cats-eye snail (subtidal bedrock 1.5-2 m)

Cats-eye abundance ranged from 1.2 to 9.6 individuals per m^2 at control sites compared to 0 to 32.7 individuals per m^2 at impact sites. At control sites, their density remained relatively stable over the duration of the study with no large increases or decreases (Figure 29). The density of snails was consistently low at Houhou Point and highest from Snake Point, Umuwheke and Double Bay. At Ngaruru and Arrowsmith impact sites, cats-eye were absent or uncommon (Figure 29). At the impact site at Allports Island, comparable densities to those recorded from control sites were regularly recorded. At the remaining impact sites, cats-eye density from deep bedrock sites regularly exceeded densities recorded from control sites.

For the pooled control treatment, mean cats-eye density peaked in May 2001 and dipped in November 2000 and March 2008, however, these high and lows were relatively small with most years showing a consistent and largely unchanged value. Cats-eye density from the pooled impact treatment was always higher compared to the control treatment but error bars overlapped in all but three sample occasions (Figure 29). The impact treatment increased relative to the control treatment, peaking in February 2006 and again in March 2008 before returning to levels regularly recorded from 2000 to 2005.

4.5.3 Topshell (subtidal bedrock 1.5-2 m)

The abundance of topshells (*Trochus* sp.) ranged from 0 to 11.2 individuals per m^2 at control sites compared to 0 to 6.6 individuals per m^2 at impact sites. At Houhou Point, Umuwheke, Double Bay and Kurakura, the density of topshells varied over the duration of the study (Figure 30). The density of topshells at all but one impact site changed little over the duration of the study. Topshells were absent or rare from Ngaruru and Arrowsmith. A relatively large increase in topshell abundance occurred at Allports Island, peaking in March 2008 and then declining in 2009 and 2010.

For the pooled control treatment, topshell density peaked in May 2001, April 2004, February 2005 and March 2008 (Figure 30). The mean topshell density for the pooled impact treatment followed the same trends as the control treatment apart from a peak in April 2004 and February 2005. Densities from the pooled impact treatment were always lower than those recorded from the control treatment, however, error bars often overlapped.

4.5.4 11 arm seastar, kina and sea cucumber (subtidal bedrock 1.5-2 m)

The density of the three target species at the pooled impact and control treatments followed similar trends over the duration of the study. Apart from one occasion (in 2010), 11 arm seastars were more abundant from the deep bedrock impact treatment compared to the control treatment. Kina density at the pooled impact and control treatment were almost identical with both increasing over the duration of the study. For sea cucumber, densities were initially higher at the control treatment, with little or no differences recorded after April 2004.

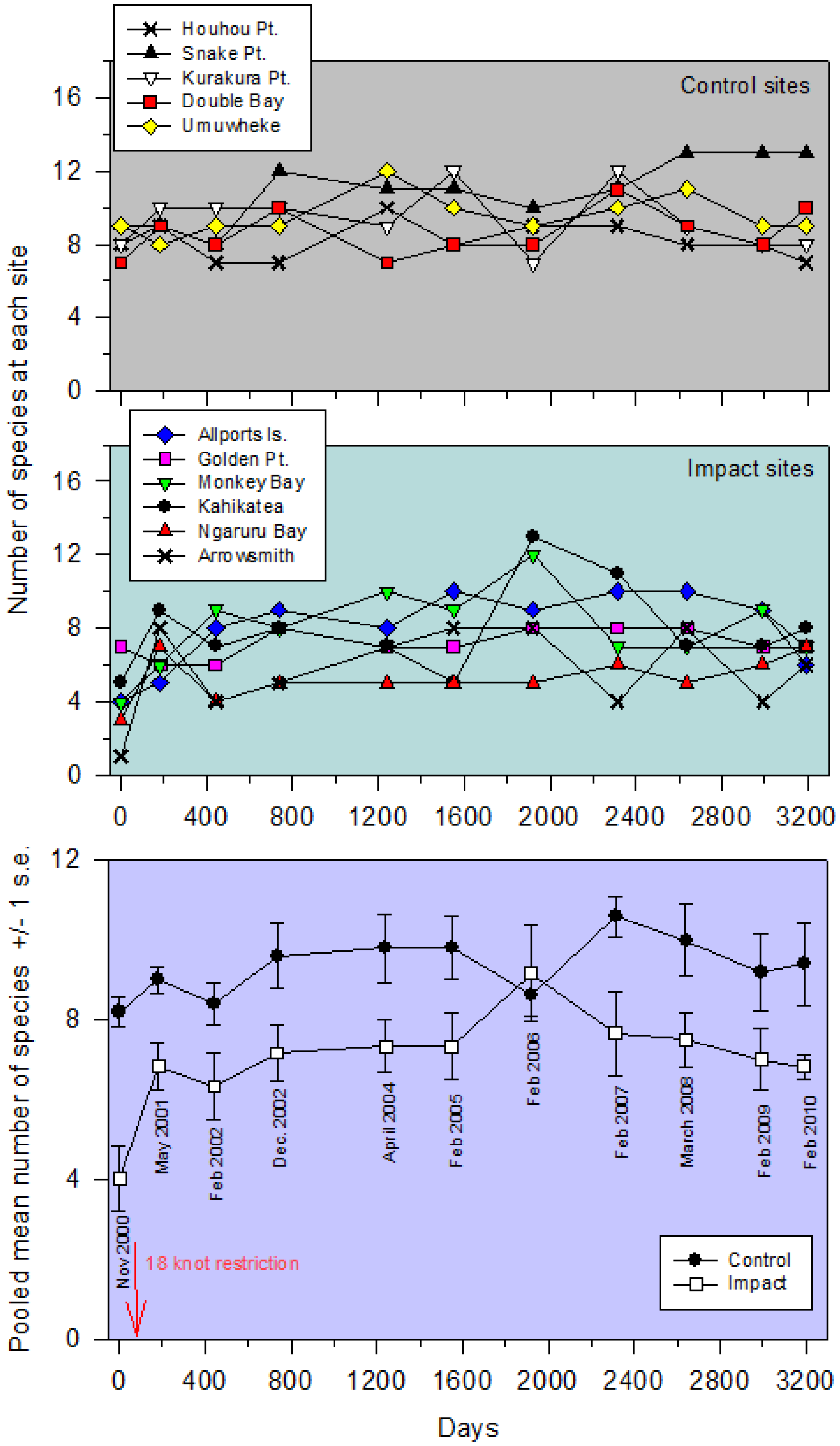

Figure 20. Number of all species recorded from shallow subtidal bedrock (0-0.5 m depth) control and impact sites and pooled treatments from November 2000 to February 2010.

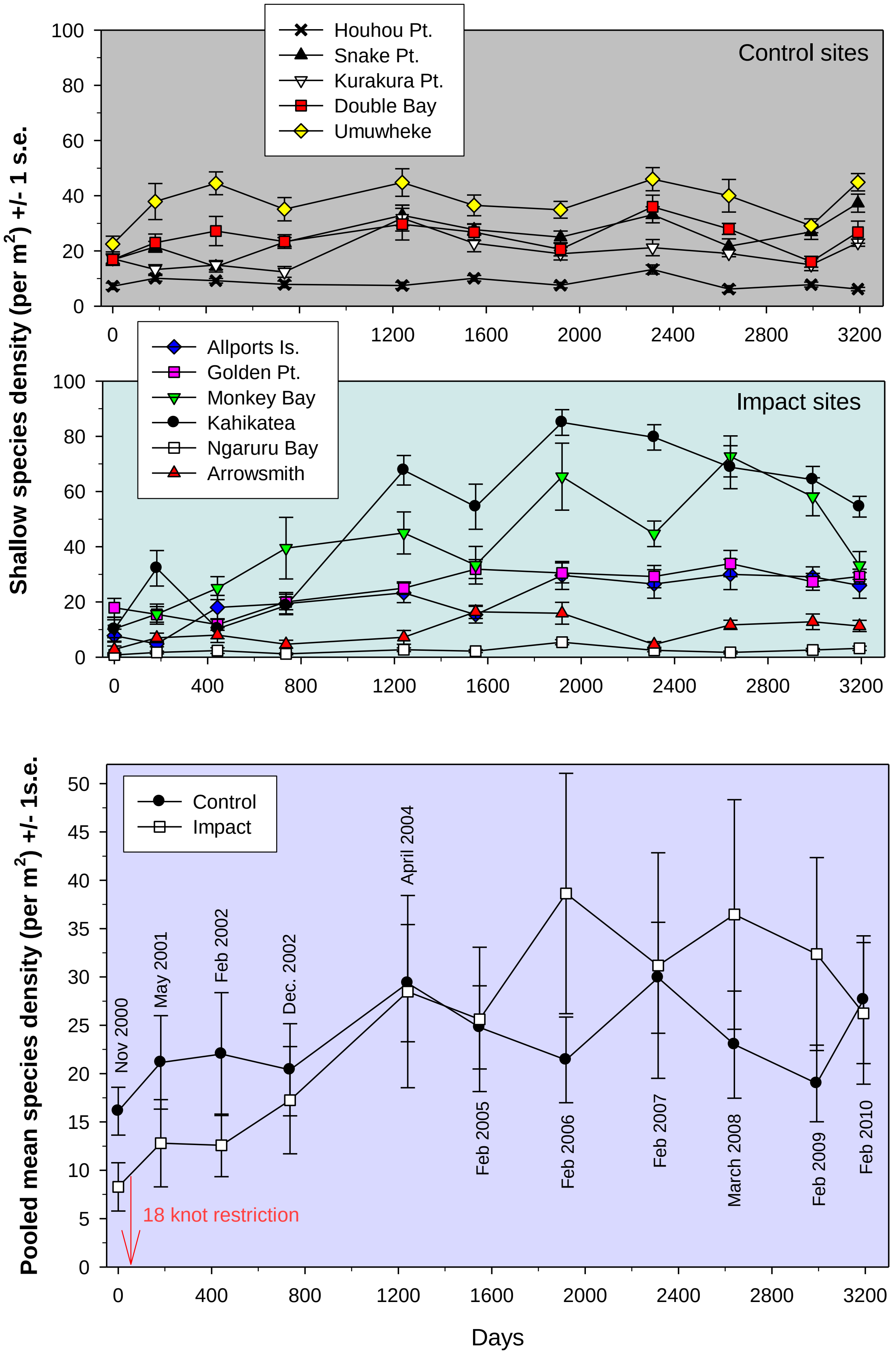

Figure 21. Mean density of all species recorded from shallow subtidal bedrock (0-0.5 m depth) control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

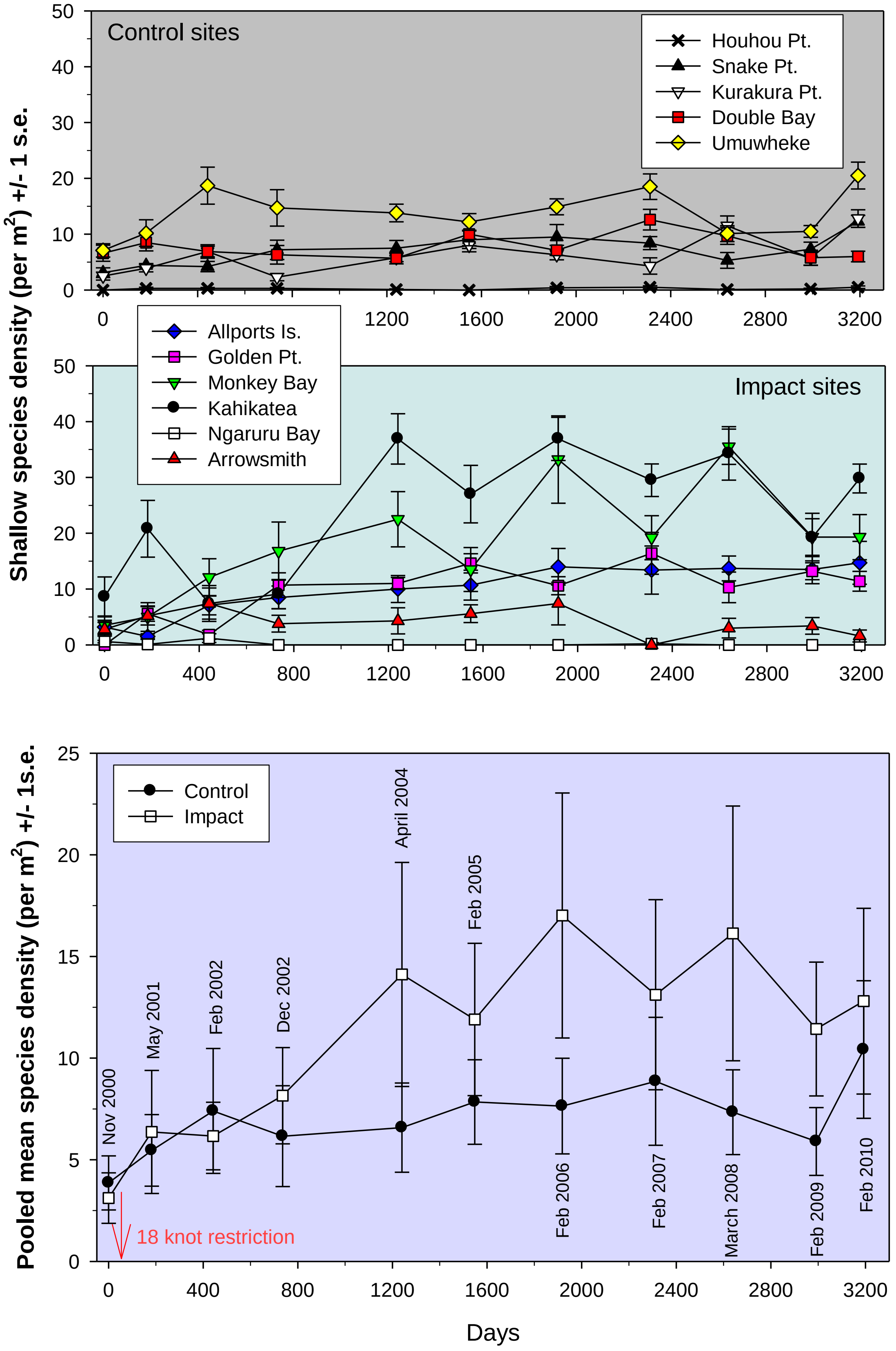

Figure 22. Mean density of kina recorded from shallow subtidal bedrock (0-0.5 m depth) control and impact sites and pooled treatments from November 2000 to February 2010.

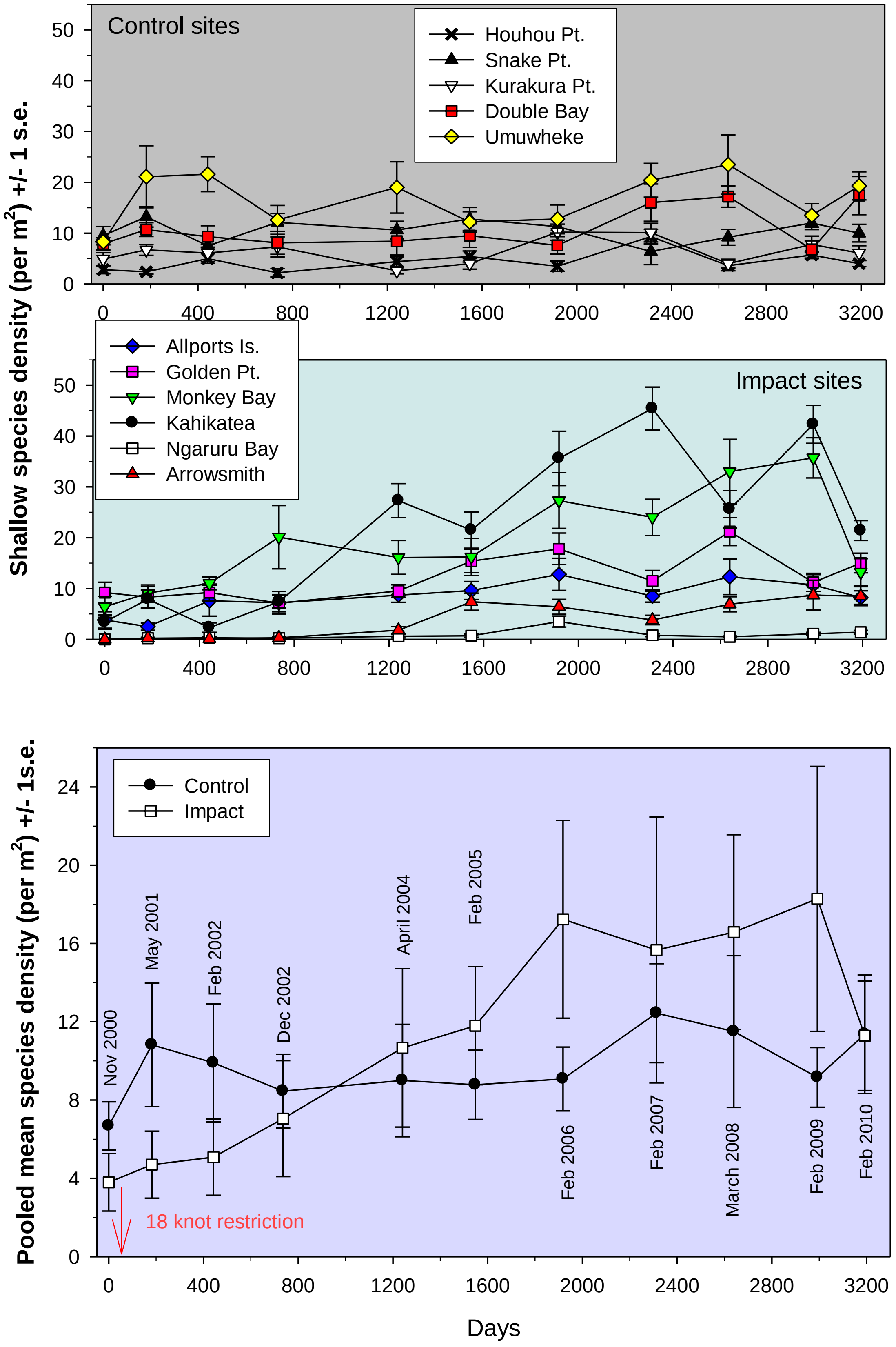

Figure 23. Mean density of cats-eye snails recorded from shallow subtidal bedrock (0-0.5 m depth) control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

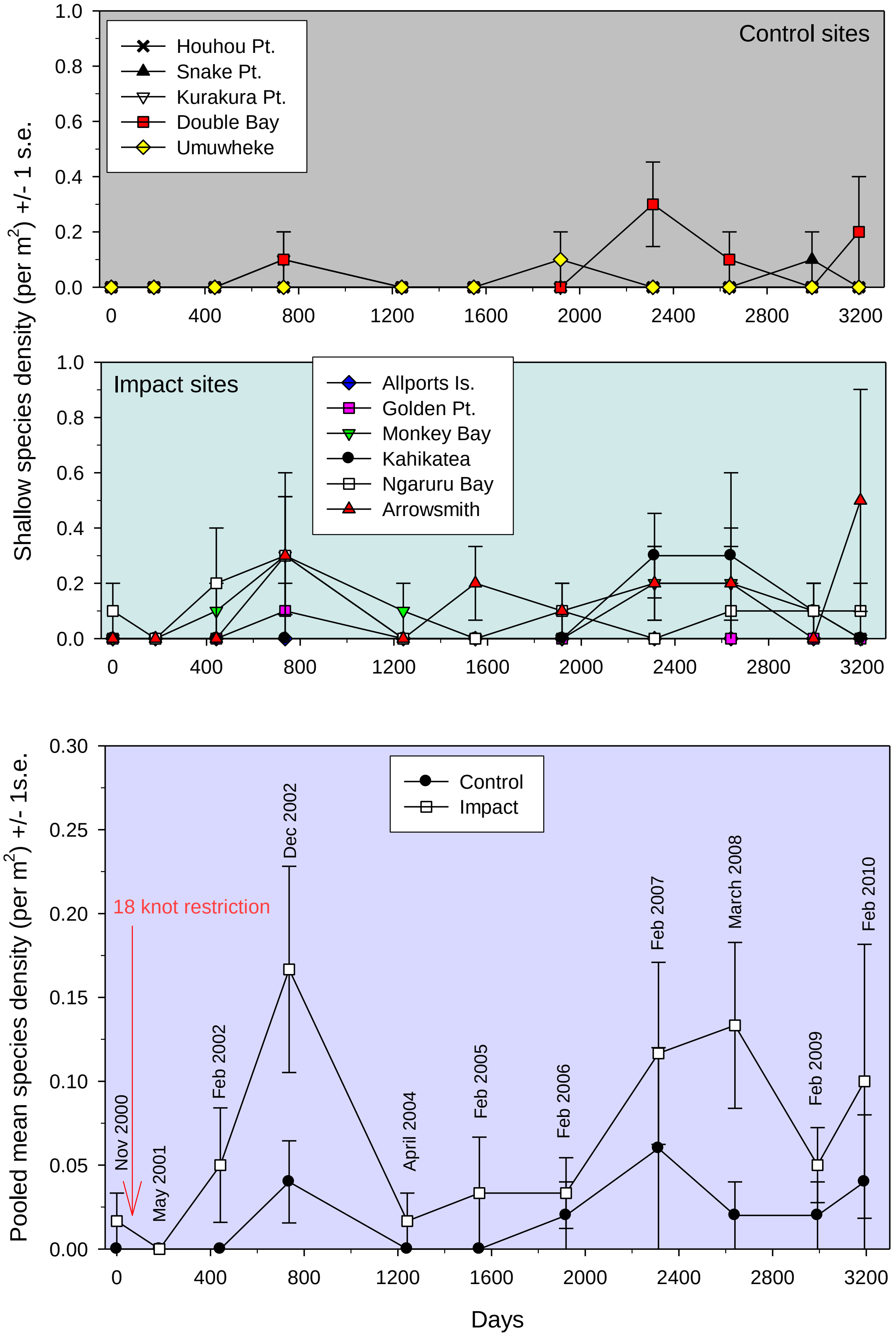

Figure 24. Mean density of black-foot paua (*Haliotis iris*) at shallow subtidal bedrock (0-0.5 m depth) control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

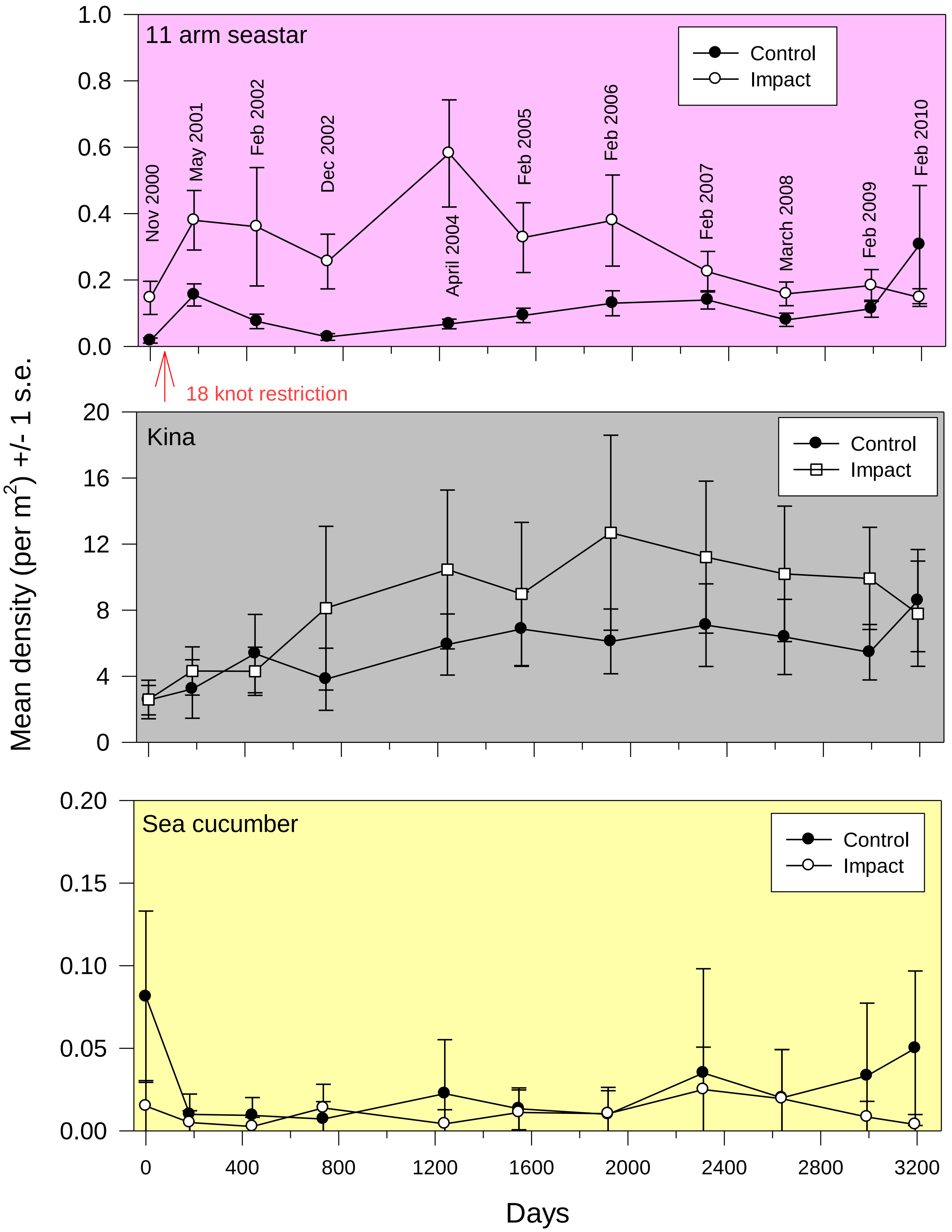

Figure 25. Mean density of three selected species recorded from shallow subtidal bedrock (0-0.5 m depth) control and impact pooled treatments from Nov 2000 to Feb 2010.

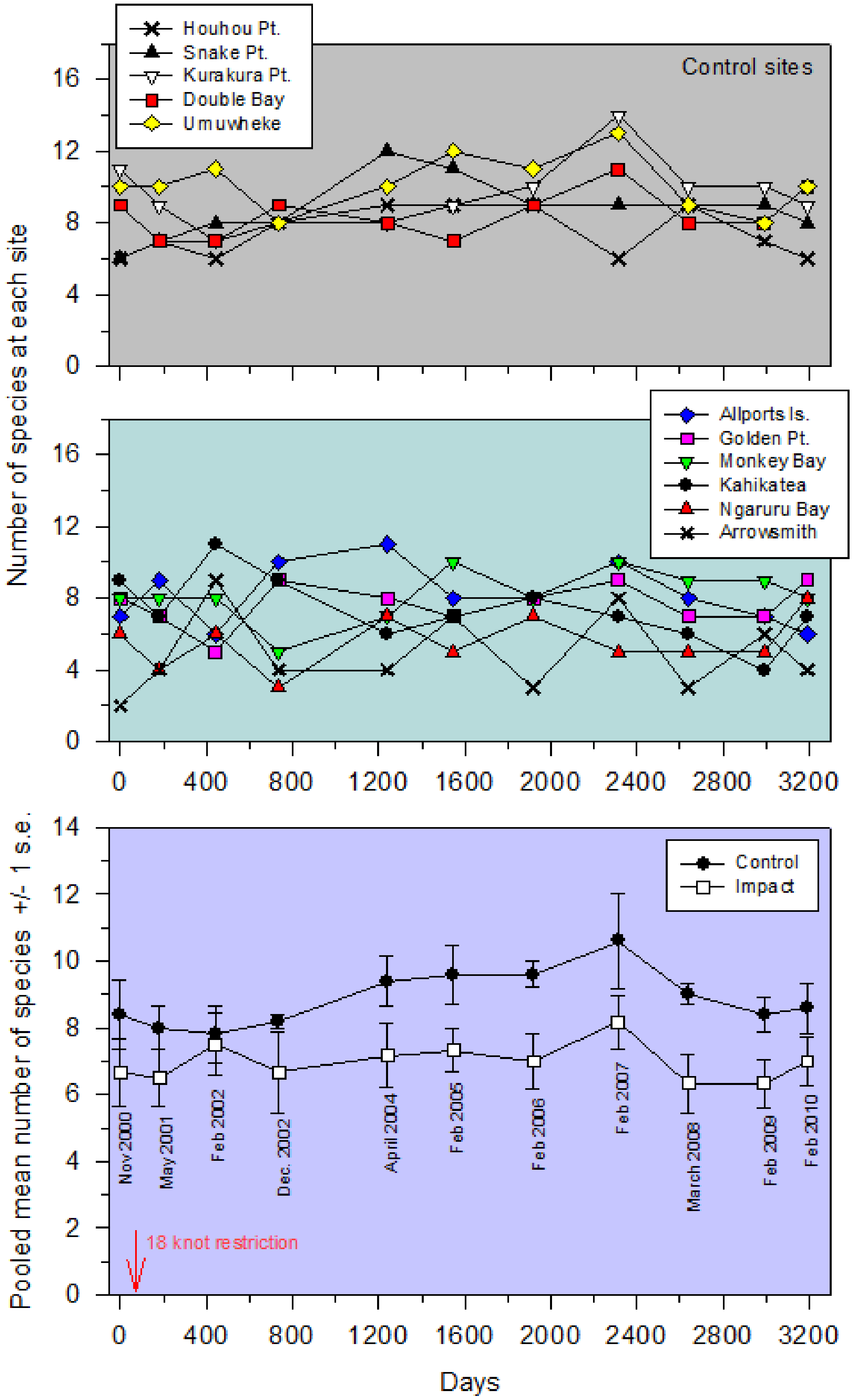

Figure 26. Number of all species recorded from deep subtidal bedrock (1.5-2.0 m depth) from control and impact sites and mean pooled treatments from Nov 2000 to Feb 2010.

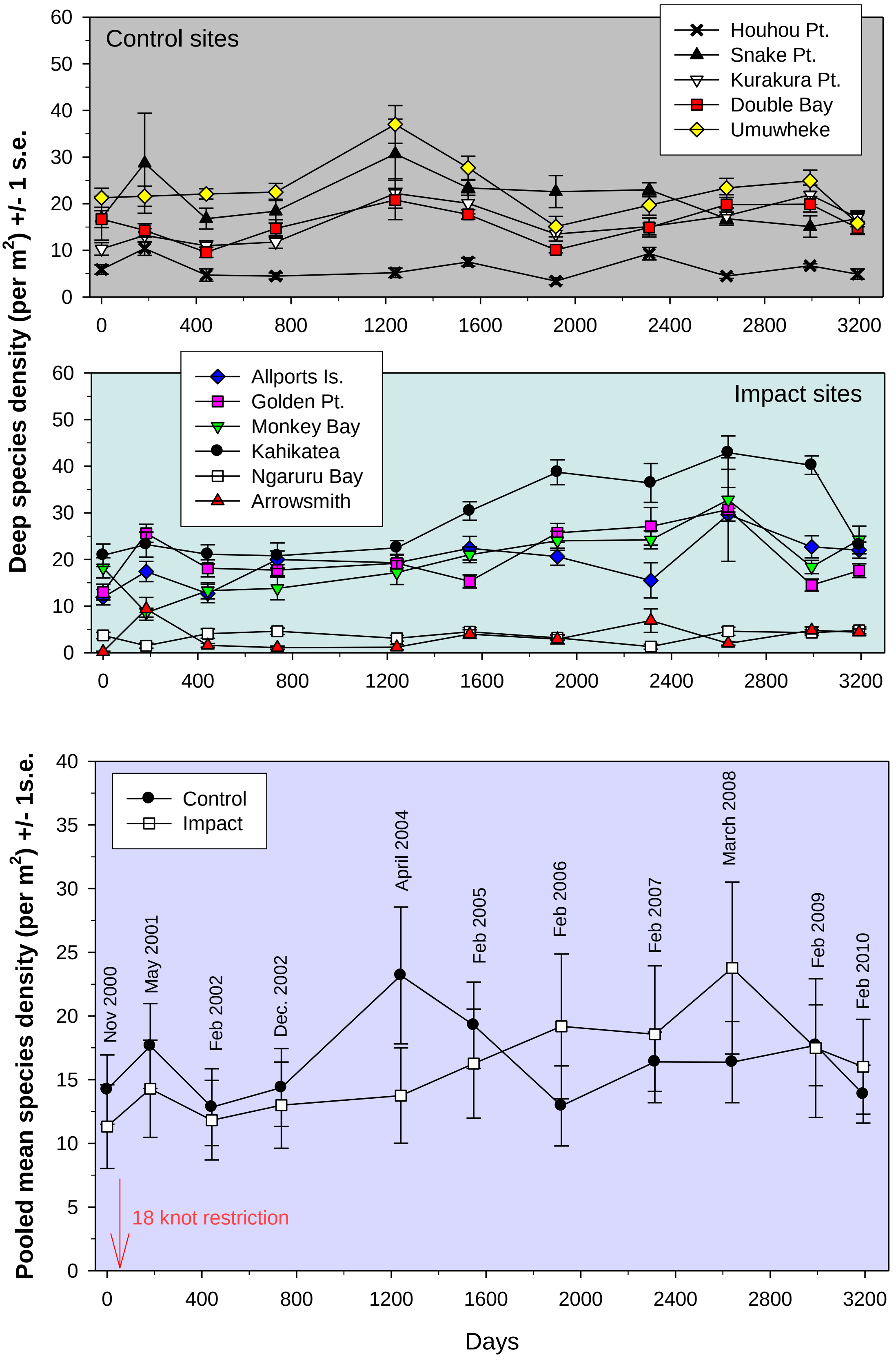

Figure 27. Mean density of all species recorded from deep subtidal bedrock (1.5-2.0 m depth) from control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

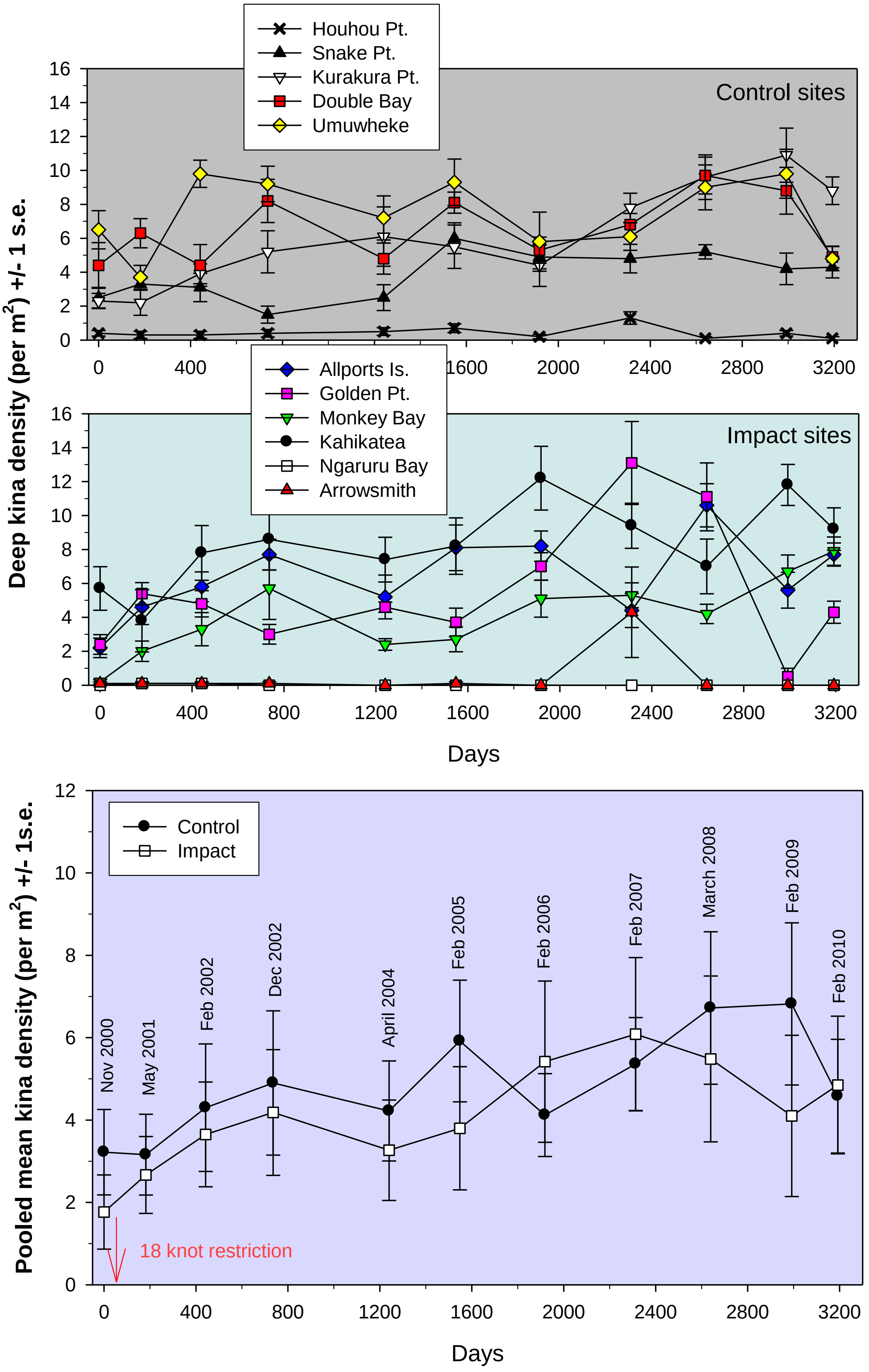

Figure 28. Mean density of kina recorded from deep subtidal bedrock (1.5-2.0 m depth) from control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

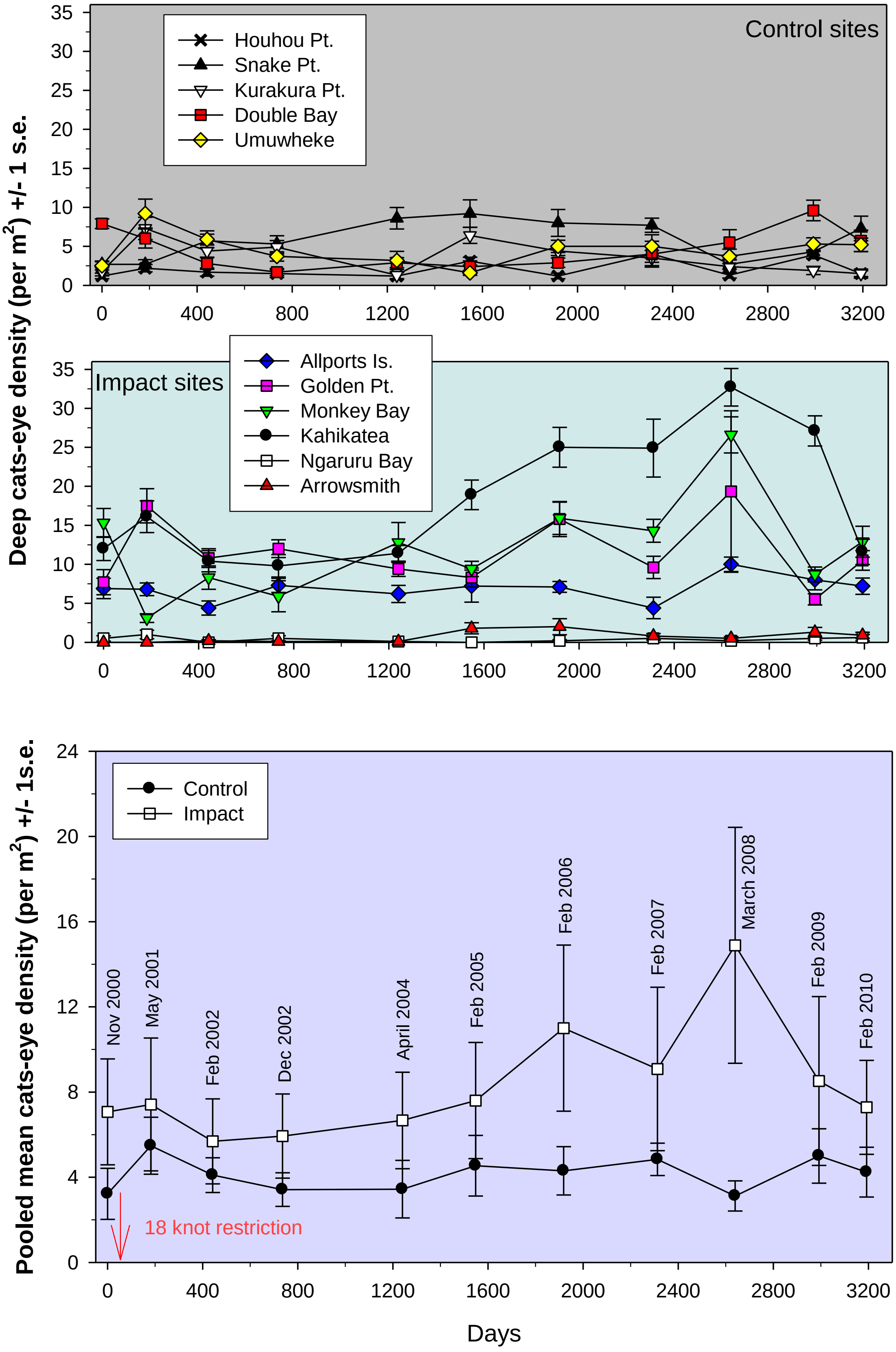

Figure 29. Mean density of cats-eye recorded from deep subtidal bedrock (1.5-2.0 m depth) from control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

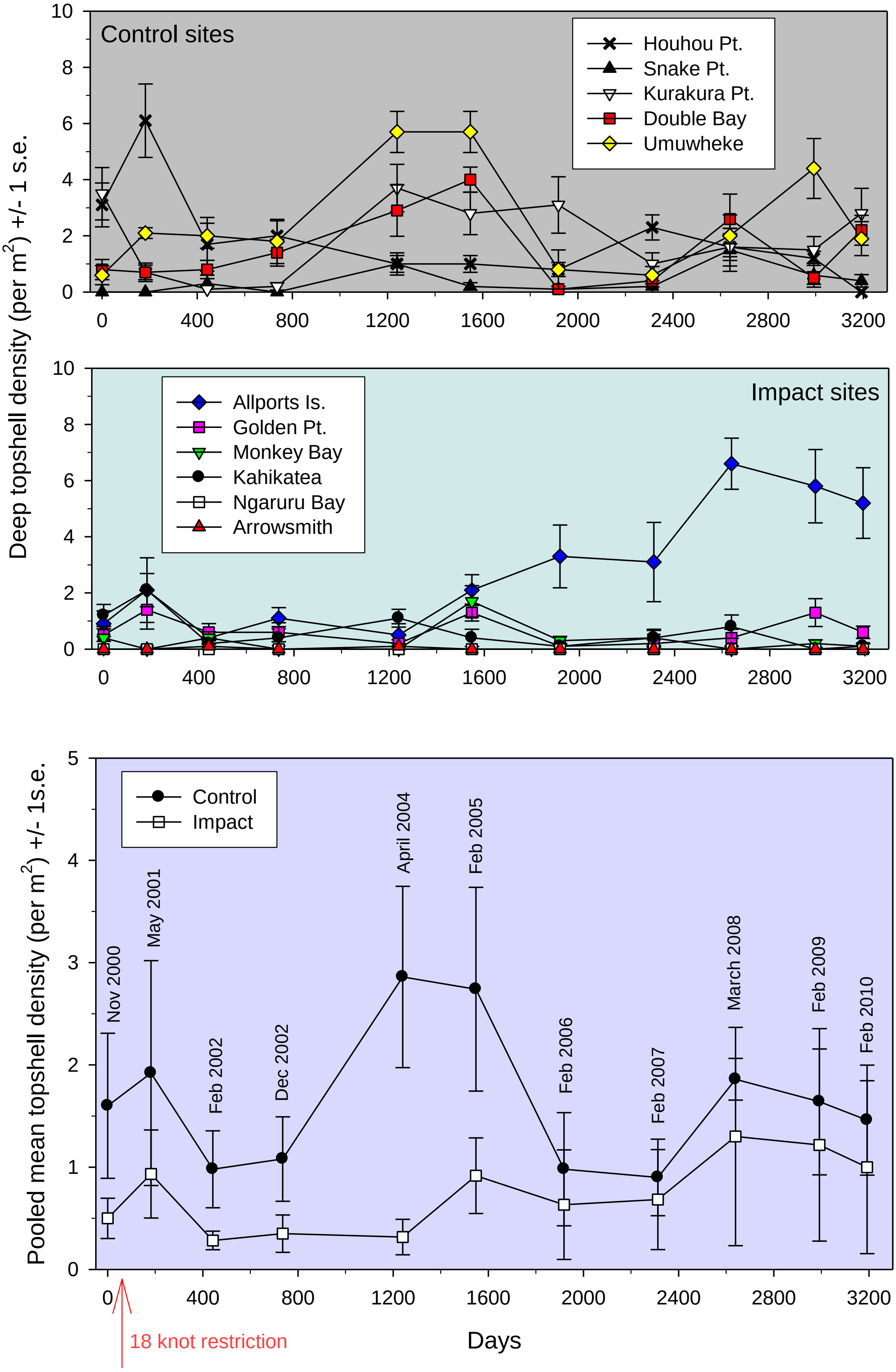

Figure 30. Mean density of topshell (*Trochus* sp.) from deep subtidal bedrock (1.5-2.0 m depth) from control and impact sites and pooled treatments from Nov 2000 to Feb 2010.

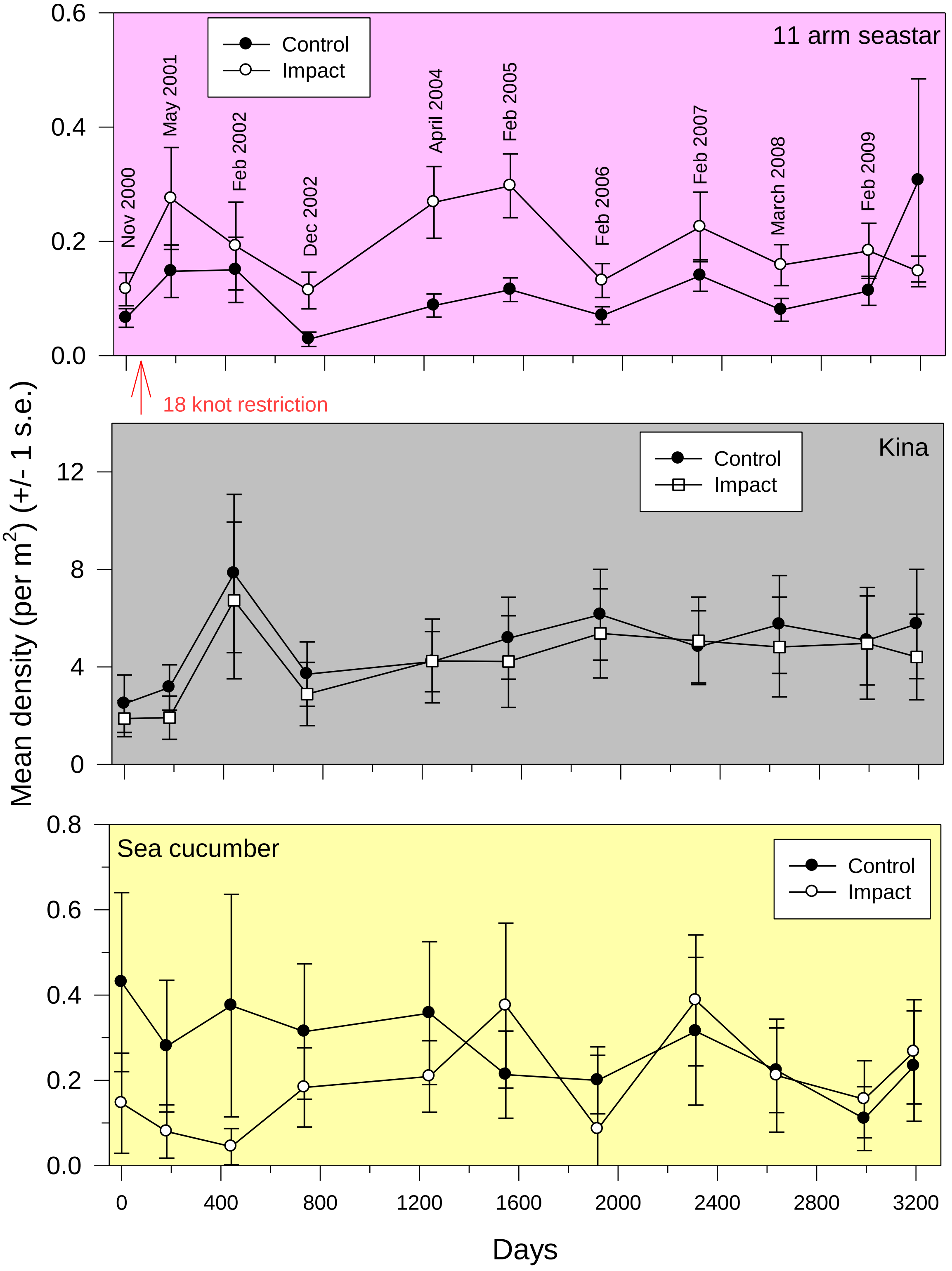

Figure 31. Mean density of selected species recorded from deep subtidal bedrock (1.5-2.0 m depth) control and impact pooled treatments from November 2000 to February 2010.

5.0 Discussion

Biological data from sites located along the ferry route through Tory Channel and Queen Charlotte Sound have been collected by a variety of authors (Davidson 1995, 1996, 1997, 1998, 2002; Davidson and Richards 2005; Gillespie 1996; Grange et al. 1995). In December 2000, a navigational Bylaw restricting high speed ferries down to 18 knots was introduced. In response, Davidson (2002) collected data in November 2000 immediately prior to the Bylaw and for the first time sampled intertidal and shallow subtidal bedrock shores. The present study updates biological data initiated in 1995 by Davidson (1995) and augmented by Davidson (2002).

Selection of control and impact sites

Control and impact sites were selected in an effort to match environmental natural variables to ensure comparability. For intertidal bedrock and cobble-small boulder shores this involved selection of shores with comparable aspects, slopes and substrata. For subtidal shores in Tory Channel this was difficult as the biological environment and associated communities are unique in the Marlborough Sounds (Davidson et al. 1995; Davidson et al. in press). One control site positioned at Houhou Point, inner Queen Charlotte Sound, was chosen in an effort to provide a control site with a cover of macroalgae. Although this site supported a lower diversity of macroalgae, the presence of a macroalgal canopy made it comparable to Tory Channel macroalgal sites.

For cobble shores, two of the three Tory Channel sites supported a low biomass of macroalgae making them similar to control site shores, however, the Tory Channel cobble-small boulder site at Te Weuweu supported a *Macrocystis* forest making it unique compared to sites located outside Tory Channel.

Davidson (2002) sampled subtidal bedrock shores at two depth strata. The author suggested that the shallow strata would potentially be impacted by ferry wash, while the deeper strata could be free from ferry wave impacts or suffer minimal wave impact due to its depth. The author stated that comparison of biological data from deeper bedrock shores would test comparability of control and impact sites. Any major differences detected between control and impact deep shores would suggest these sites were naturally different and therefore unsuitable for use. Davidson and Richards (2005) reported that between 2000 and 2005 relatively little difference between impact and control sites were apparent. Data collected since 2005, confirms that deep bedrock impact and control sites are little different. This also suggests that these impact sites are free from ferry-induced impacts. The use of these control sites to determine the scale of any impacts at shallow subtidal and intertidal shores at sites subjected to ferry wakes is therefore valid.

Cobble-small boulder (intertidal)

The number of species and their density were sampled from intertidal cobble-small boulder shores from March 1995 to February 2010. The 15 year sampling regime at control sites provides a relatively reliable description of species diversity and density for central Queen Charlotte Sound. At both tidal heights at control sites, the number of species and their density were variable with an occasional extreme event that stepped outside the normal range of values. When this occurred, values quickly returned into the normal range. The reason for these abnormal one-off events is unknown, but may be related to storms or prolonged periods of hot, stable weather combined with small tides resulting in mortality or migration due to heat stress.

Number of species and density at control sites (and for pooled data) were always higher at control sites compared to impact sites. The number of species and the density of invertebrates at impact intertidal shores increased after the Bylaw, suggesting that pre-Bylaw values were due to elevated wave energy produced by high speed ferries. Prior to the Bylaw, most cobble and small boulder substrata at impact sites were regularly rolled and overturned (Davidson 1995, Grange et al. 1995). For example, at Arrowsmith and Picton Point, regular wave action sufficient to move cobbles resulted in a jumbled, loosely packed intertidal shore characterised by a relatively mobile substrata compared to control sites where cobbles were usually stable and surrounded by finer substrata such as pebbles, broken shell and sand. Eventually cobbles at impact sites appeared similar to boulders on a braided river bed (i.e. with little or no encrusting biota) (Plates 1 and 2). In these conditions, the biota living on and under cobbles became rare or absent.

Intertidal cobbles at control sites were also disturbed by waves created by natural events such as storms and an occasional passing of a ship. These events create waves with a higher energy than normal conditions. These storm-induced waves move cobble and small boulder substratum as indicated by the occasional presence of pink coralline encrusted rocks in the intertidal zone. At impact sites, coralline covered rocks relocated into the intertidal zone by waves were a regular occurrence at impact sites prior to the Bylaw (Plate 1). This phenomenon also occurred after the Bylaw and after higher speed ferries ceased operation, but at a reduced level (Plate 3).

Plate 1. Intertidal cobble shore located at Picton Point, 1995. Note pink coralline encrusted rocks that have originated from the subtidal and jumbled clean cobbles.

The principal difference between cobble-small boulder control and impact shores was the frequency and scale of substratum disturbance. Storm events occur relatively infrequently in the Marlborough Sounds and their impact will depend on wind direction and fetch distance. In contrast, ferries pass through the Sounds multiple times each day. Following the introduction of the Bylaw, waves produced by fast ferries were smaller (Croad and Parnell 2002). Reduced disturbance of substrata is the most probable explanation for the increase in the density and abundance of invertebrates at intertidal cobble-small boulder shores along the ferry route. This change did not occur at the control sites where the number of species and their abundances remained within the normal range of variation.

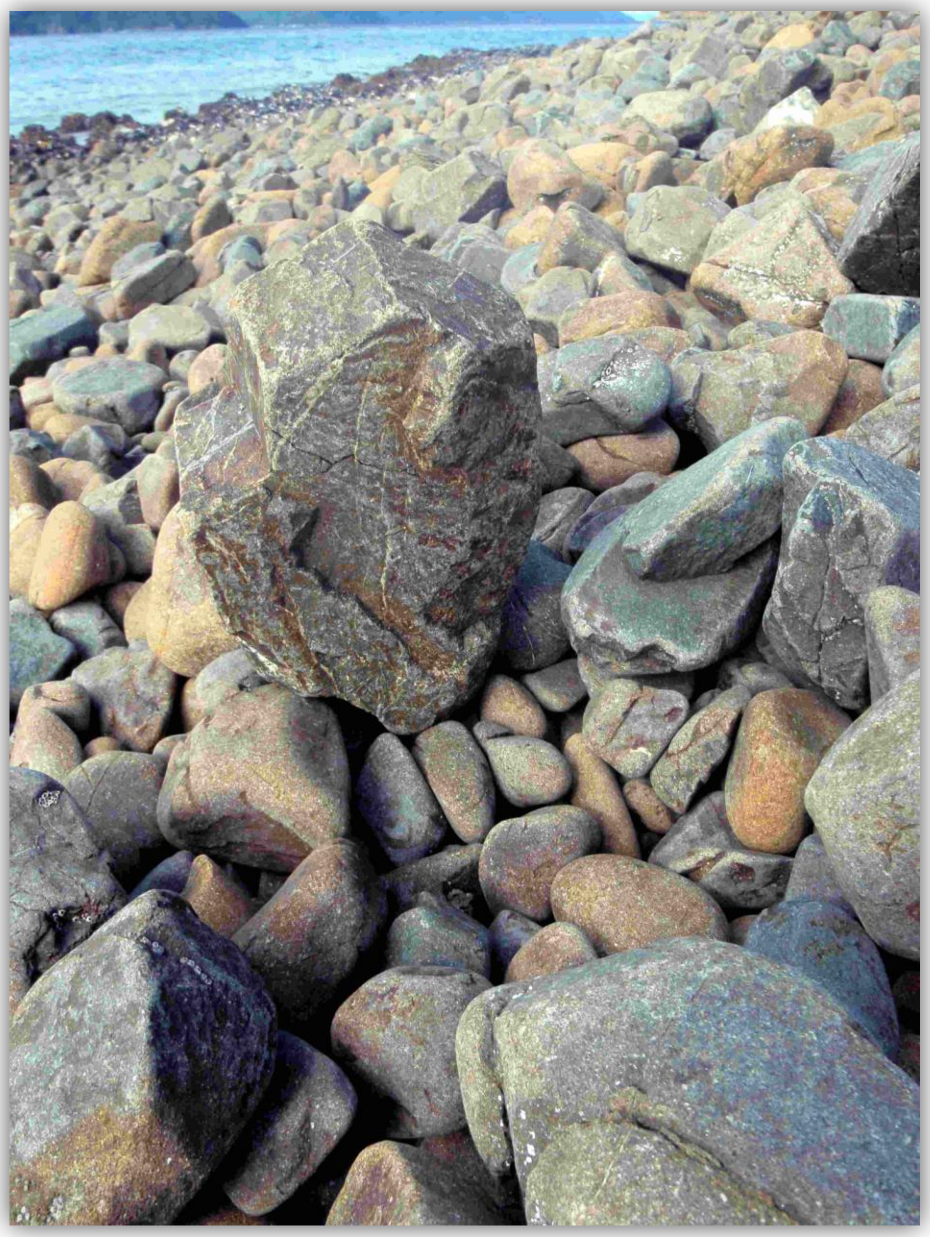

Plate 2. Intertidal mid-tide cobble shore, Picton Point, January 2010. Note: jumbled clean appearance of cobbles and a lack of fine substrata such as sand, broken shell and pebbles.

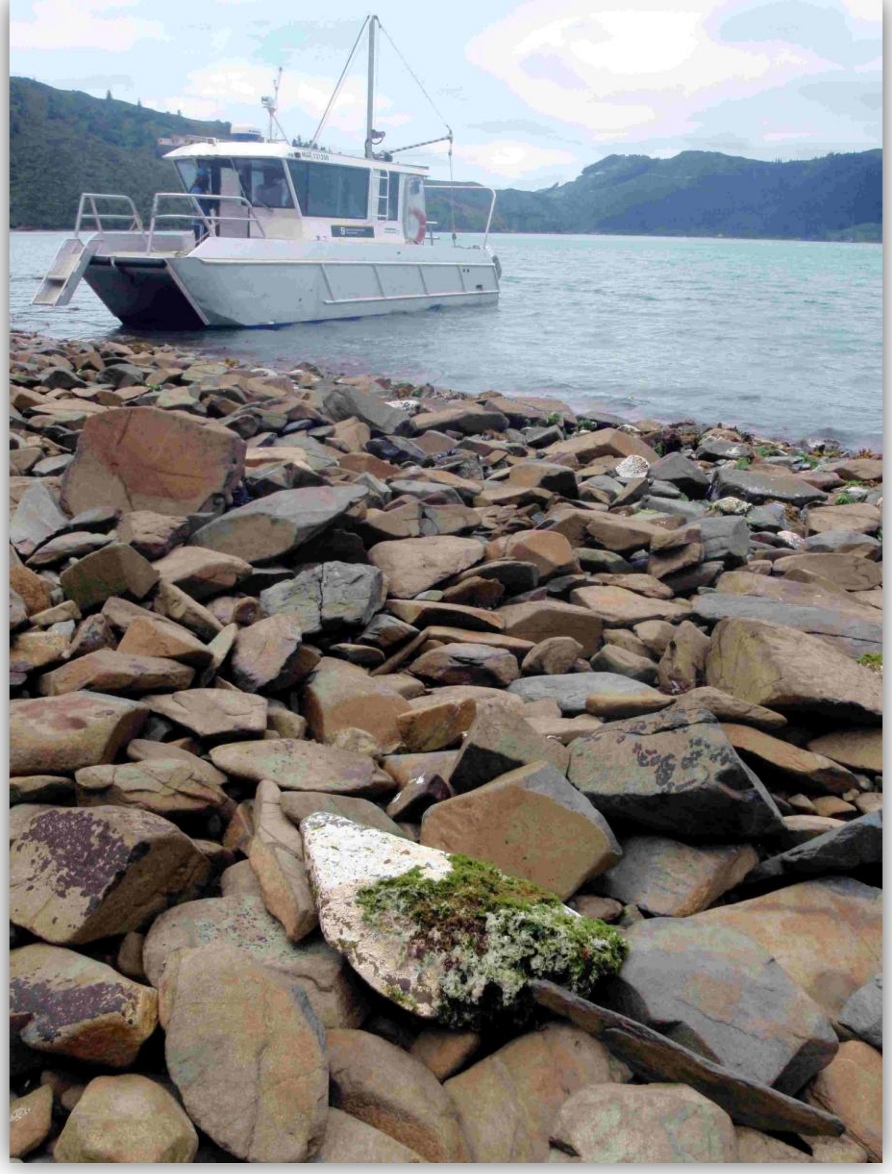

Plate 3. A coralline encrusted cobble at mid-tide, Arrowsmith, January 2010.

An increase in the number of intertidal species at cobble-small boulder impact shores has continued until 2010 but still remains below control levels. In contrast, the density of molluscs steadily increased until the summer of 2005 followed by a decline at both tidal heights. This decline coincided with the introduction of the largest ferry, the Challenger (Kaitaki), in late 2005 (Appendix 1). The failure of the recovery to reach control levels suggest that waves produced by conventional ferries impact these shores.

Cast animals

The phenomenon of cast subtidal invertebrates into the intertidal zone is a natural phenomenon due to waves. During periods of increased wave energy such as storms, subtidal animals are cast onto the intertidal shore and those unable to migrate down the shore will die. In the case of animals strongly attached to cobbles such as paua, it appears they are not detached, rather they are cast ashore still attached to the cobble during high energy events. Few subtidal animals migrate into the intertidal or high tide drift line when the tide is full leaving waves the only explanation to this occurrence.

The number of macroinvertebrate species and their abundance cast into the intertidal were sampled between July 1995 and February 2010. Control sites were spread over a relatively large area with a variety of shore aspects and fetch distances. Clark Point was the eastern-most site and is exposed to the predominant north-west winds, while Blumine south is a small, south-facing bay with very small fetch distances. Clark Point often had kina washed ashore, but relatively few other species were observed from quadrats, while Blumine south seldom had any animals within sample quadrats. Double Bay often had the highest number of species and densities of invertebrates for any control site. Double Bay is also exposed to the predominant north-west wind. Pooled control treatment data suggested that the number of species washed ashore is relatively stable with no major peaks or troughs and is a factor of exposure to storm-induced waves.

In contrast, the number of species at impact sites was often higher and had elevated peaks compared to controls. This phenomenon was more often recorded prior to the Bylaw during the period that fast ferries produced relatively large set of waves (Plates 5 and 6). Both Onapua and Te Weuweu impact sites have relatively small fetch distances and are sheltered from the north-west winds. The impact site at Dieffenbach is exposed to the predominant north-west winds, but has a north-west fetch distance comparable to Clark Point, Double Bay and Blumine (north) and should therefore show comparable values to these control sites. The elevated number of species and densities of cast invertebrates from these impact shores is best explained by increased wave energies created by ferries (Plate 4).

Following the introduction of the Bylaw, the peak values recorded at impact sites during the first 600 days of the study were not repeated. Peaks at impact sites above control levels have occurred after the Bylaw, but their magnitude is dramatically lower than those recorded immediately after the arrival of the fast ferries. It is probable that the number of invertebrates cast ashore declined as the densities of animals living in the shallow subtidal also declined.

Plate 4. Recently cast kina at the high tide drift line at Te Weuweu 1995. Note: spines and flesh are intact for most individuals suggesting recent relocation from the subtidal shore.

Cobble-small boulder (subtidal)

Kina and black-foot paua abundance were monitored at shallow subtidal cobble-small boulder sites between February 1995 and 2010, while cats-eye densities were sampled between November 1995 and February 2010.

The abundance of kina at the eastern-most control sites (i.e. Clark Point and Long Island) was always highest and the most variable compared to the other three control sites. All control sites located further into Queen Charlotte Sound supported lower densities and less variability. This pattern of abundance may be related to environmental factors such as food availability, with more macroalgae present at Clark Point compared to other control sites.

At impact sites prior to the Bylaw, the density of kina was relatively low compared to controls. Following the introduction of the Bylaw, kina densities at two of the five impact sites (i.e. Onapua and Monkey Bay) increased to levels well above values recorded during the first six years of the study. A corresponding increase at control sites did not occur and it is most likely that this increase at impact sites was due to a wave reduction from fast ferries. Following the highs recorded for the pooled impact treatment between 2004 and 2006, a decline to kina density occurred. This decline also occurred at control sites suggesting this was not related to ferry wakes but was instead a natural environmental factor. Future monitoring will determine if this decline was due to a natural or ferry-induced impact.

A range of cats-eye densities were recorded at individual control sites, but each site often remained relatively consistent over the duration of the study. Unlike the abundance pattern recorded for kina, cats-eye snails were least abundant at the two eastern-most control sites (i.e. Clark Point and Long Island) compared to the sites located further west. At impact sites, large cats-eye density peaks recorded early in the study declined to very low levels prior to the Bylaw, after which numbers increased at most sites suggesting a reduction of wave energy was beneficial for this species. Overall, the abundance of cats-eye have continued to increase at shallow subtidal cobble sites subjected to conventional ferry wakes, with pooled densities increasing above levels recorded at the control treatment. This suggests that a moderate level of wave exposure from conventional ferries is beneficial to this species and/or that impact sites naturally support higher densities. It is impossible to determine which explanation is most plausible as no pre-conventional ferry data is available.

Paua were absent or rare from most control sites and, although present at a greater proportion of impact sites, they were also uncommon over the duration of the study. The exception was the control site located at Clark Point where they were always present in relatively high densities in most years compared to both impact and control sites. The reason for their higher abundance at this site is probably related to the presence of food supply in the form of sea lettuce beds growing in the shallows. No increase in the density of paua occurred at impact sites after the speed restriction. The reasons for the lack of a recovery at impact sites are unknown.

Plate 5. Waves from the Condor 10 arriving at Picton Point, 12 January 1996.

Plate 6. Waves from the Condor 10 arriving at Bobs Bay, Picton Harbour, January 1996.

Bedrock (intertidal)

Only mollusc species that are easily detached by waves were selected for study. Species such as limpets were not sampled as they cannot be dislodged from bedrock surfaces by waves generated by ferries or storms.

The number of intertidal species at some control and impact sites gradually declined over the duration of the study. This decline was most obvious for the pooled data for each treatment. As this decline occurred at both treatments, it is likely that it was due to natural environmental factors. In all years the number of “mobile” intertidal bedrock invertebrate species was higher at control sites; however, the difference was relatively minor suggesting ferry wakes have not greatly reduced species diversity on bedrock shores. Of note, however was the low range of species recorded at the south-facing, near-vertical bedrock sites in Tory Channel (i.e. Tory and Ngaruru) compared to the higher species diversity at comparable south-facing control rock faces (i.e. Blumine south and Kurakura). Observations of ferry wakes arriving at these vertical walls suggest their impact is greater compared to gently sloping shores like Monkey Bay and Arrowsmith where a higher number of species were recorded.

The density of intertidal “detachable” molluscs from control sites was highest from the three north-facing sites of Umuwheke, Double Bay and Snake Point. Similarly, north-facing impact sites supported highest densities of “detachable” molluscs although the scale of the difference was less dramatic compared to control sites.

In the first four years of the study, dramatically more molluscs were recorded from the control treatment compared to the impact treatment. Following the Bylaw, impact mean values steadily increased for five consecutive years. An increase also occurred over the same period for control treatment. This control increase ended one year earlier than the impact treatment and represented a much smaller scale of increase that was not consecutive with a control dip recorded in April 2004. Following the control peak in February 2005, mollusc density dropped back to levels recorded at the start of the study.

Pooled impact values have remained lower than values recorded at the control treatment, however impact values increased well above levels recorded prior to and immediately after the Bylaw. The increase suggests that waves generated by unrestricted fast ferries greatly reduced the density of “detachable” molluscs from bedrock shores. Densities however, remain well below those recorded at the pooled control treatment suggesting that waves produced by conventional ferries limit abundance of “detachable” molluscs, but not at the scale imposed by unrestricted fast ferries.

At impact sites, the density of particular mollusc species such as oyster borer and topshell were well below those recorded from control sites suggesting that ferry wakes have had, and still have, an impact on their abundance. For both these species, an increase after the introduction of the Bylaw suggests that unrestricted fast ferries had a major impact on their abundance and that slowing these ferries allowed their recovery. This recovery peaked in February 2006 and was followed by a decline to intermediate levels between the 2006 peak and the lows recorded at the start of the study. This abundance decline coincides with the introduction of the Challenger (Kaitaki) prior to the 2006 sample event.

Cats-eye densities were highly variable at control sites with peaks and crashes recorded throughout the study. At impact sites, even larger peaks followed by population drops were observed. The highly variable abundance of this species on intertidal bedrock control shores makes it a poor candidate to investigate the impact of waves from ferries as any changes are confused by the high natural variability.

Bedrock shores (deep subtidal)

Deep subtidal bedrock shores (1.5–2 m depth) located along the ferry route were little different to control sites located away from the ferry route. This suggests that waves generated by these ships do not impact deeper bedrock shores. Observations by divers as waves from unrestricted fast ferries and conventional ferries arrive at these shores showed that disturbance occurred, but the scale of disturbance was dramatically less than at shallower depths. Divers could maintain their position at depth, whereas divers were often rolled or overturned in the shallows.

Bedrock shores (shallow subtidal)

The number of species recorded from shallow subtidal bedrock at control sites remained relatively stable over the duration of the study. In contrast, the number of species at almost all impact sites increased after the Bylaw from initial low levels suggesting that unrestricted fast ferries reduced the number of species at these shores. The number of species at the pooled impact treatment increased for five years peaking in February 2006 before declining to moderate levels over the subsequent four years. The decline in the number of species at the impact treatment suggests that conventional ferries have an impact, but not at the level of unrestricted fast ferries. This decline also coincides with the introduction of the Kaitaki.

The density of shallow subtidal bedrock species at impact sites followed a similar pattern with initial lows followed by a consistent increase for five years peaking in 2006 and followed by a decline to a moderate-low level in 2010. The scale of the abundance increase for the impact treatment was dramatic, with a more than a four-fold increase over a period of five years. Again, this suggests that unrestricted fast ferries had a major impact on shallow subtidal communities. Between 2006 and 2010, the abundance of invertebrates at control sites remained relatively stable but declined for the impact treatment. Again, this suggests an impact by conventional ferries but not at levels recorded by unrestricted fast ferries.

Both kina and cast-eye densities exhibited a pattern starting with initial low densities followed by a consistent increase for five years after the introduction of the Bylaw to levels above those recorded at the control treatment. For these species, densities have remained at or higher than those recorded for the control treatment suggesting that these species at shallow bedrock shores are not adversely impacted by conventional ferries. Black-foot paua were present in very low densities and their abundance varied considerably between sample events. Based on their low abundance combined with the between-year variability, no conclusions in relation to ferry impacts are possible.

6.0 Conclusion

When fast ferries first arrived in the 1994-1995 summer season, many Marlborough Sounds residents complained of a dramatic increase in wave size. It was also argued that unrestricted fast ferries had an adverse impact on biological communities in sheltered shores of Tory Channel and Queen Charlotte Sound. Following a hearing initiated by a community group called “Save the Sounds, stop the wash”, The Environment Court stated that an adverse biological impact could not be proven due to a lack of before fast ferry data (NZ Planning Tribunal, 1995). Further, that the fast ferries were forming a “new equilibrium” comprising both conventional and fast speed vessels.

The present study provides evidence of a biological recovery at intertidal cobble-small boulder, bedrock and shallow subtidal shores along the ferry route once fast ferries were restricted to a maximum speed of 18 knots (Table 2). This recovery occurred for many species at many impact sites, but this pattern did not occur at control sites. In some cases, the scale of the increase was dramatic at impact sites. For example, at shallow subtidal shores the increase pushed values above those recorded from the control treatment. At no time prior to the speed restriction did intertidal and shallow subtidal shores support more species at higher densities than were found at control sites and in most cases dramatically lower numbers were found at impact sites. For intertidal cobble-small boulder shores, the magnitude of the impact from unrestricted fast ferries was extreme. At these shores, the number of species and their abundance often approached complete local extinction. There is no other plausible explanation for this recovery other than slowing fast ferries to 18 knots. Clearly it has taken 15 years of surveying to show that the concerns voiced by the local Sounds residents in the summer of 1994-95 were correct and that the "new equilibrium" for the Sounds was representative of a major adverse environmental impact.

After the Bylaw, a recovery occurred and in the absence of any ferries, the recovery should theoretically continue until impact sites supported biological communities comparable to those recorded at control sites. For many species and sites, biological communities remain well below those recorded at controls. This suggests that waves produced by conventional ferries have an impact at particular sites and upon certain species. A subdued recovery has occurred for intertidal cobble-small boulder shores, for mollusc density at intertidal bedrock shores, and for most species at shallow subtidal shores. For example, a pattern of recovery peaking in or around 2005 followed by a decline occurred at intertidal cobble-small bolder and bedrock shores (Table 2). The failure of the recovery to reach control levels and the decline in species diversity and abundance after 2005 suggests an adverse impact from conventional ferries. It is of note that the peak recovery values recorded for the impact treatment and subsequent formation of a declining trend coincided with the introduction of the largest conventional ferry (Challenger or Kaitaki), which entered service in late 2005.

Shallow subtidal shores were impacted by unrestricted fast ferries; however, the number of species and their abundance after the Bylaw increased and have remained at comparable or higher levels than those recorded from pooled control treatments. This suggests that these shore types are not adversely impacted by conventional ferries with moderate levels of wave energy benefiting some species.

Continued monitoring of all shore types is recommended to further assess the scale of the trending decline at some intertidal sites and to follow the recovery at subtidal shores.

Table 2. Summary of biological monitoring in relation to 18 knot bylaw and operation of conventional ferries.

Shore type	Biological feature	Impacted by fast ferries	Change after bylaw attributed to wakes	Negative impact conventional ferries	Status 2010
Cobble (intertidal)	Species	Yes	Increase (most sites)	Yes	Stable, below control
Cobble (intertidal)	Mollusc density	Yes	Increase (some sites)	Yes	Declining 2006-2010
Cobble (intertidal)	Cast invertebrates	Yes	Decrease	Minor	Stable
Cobble (subtidal)	Kina	Yes	Increase (2 sites)	Minor	Stable
Bedrock (intertidal)	Mobile molluscs species diversity	Minor	No	No	Stable
Bedrock (intertidal)	Mobile mollusc density	Yes	Increase (most sites)	Yes	Stable
Bedrock (deep subtidal)	All	No	No	No	Stable
Bedrock (shallow subtidal)	Number of species	Yes	Increase (most sites)	Yes	Declining trend
Bedrock (shallow subtidal)	Pooled density	Yes	Increase (most sites)	Yes	Declining trend
Bedrock (shallow subtidal)	Kina density	Yes	Increase (most sites)	No	Stable
Bedrock (shallow subtidal)	Cats eye	Yes	Increase (most sites)	No	Drop (1 event)
Bedrock (shallow subtidal)	Black-foot paua	Unknown	Unknown	Unknown	Low abundance, variable

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Appendix 1. Operational periods for ferries from 1994 to 2007.