Davidson Environmental Limited

Biological monitoring of the ferry route in Tory Channel and Queen Charlotte Sound: 1995-2017

Research, survey and monitoring report number 854

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Summary

1. A variety of conventional ferries have travelled between Picton and Wellington from 1962 to the present day. High speed ferries operated along the same route from late 1994 to mid-2005. When fast ferries arrived, many Marlborough Sounds residents complained of an increase in the size and energy of ferry wakes and consequential impacts on sheltered shore biological communities. On 15th December 2000, the Marlborough District Council implemented a Navigation Bylaw restricting fast ferries inside the Sounds to a maximum speed of 18 knots unless they could adhere to a "wash rule".
2. This present report compares biological monitoring data collected between 1995 and 2017 from intertidal and subtidal bedrock and cobble-boulder sites along the ferry route (impact sites) and away from the ferry route (reference sites). Sites were all located in the relatively sheltered waters of Tory Channel and Queen Charlotte Sound.
3. Ecological recovery of certain biological metrics was documented at many impact sites (i.e. intertidal and subtidal cobble-small boulder shores and intertidal and shallow subtidal bedrock shores) following the Bylaw. As similar changes were not recorded at reference sites, the most plausible explanation is the reduction in wave energy once the fast ferries slowed down or ceased operation.
4. At some subtidal bedrock impact sites, the recovery surpassed reference site levels. However, some intertidal bedrock and cobble shores exhibited limited recovery, most likely because of continued waves from conventional ferries.
5. It is recommended that biological monitoring is continued to assess the ongoing impact of conventional ferries, including any future changes to the composition or operation of the Cook Strait ferry fleet. It is also recommended that the frequency of sampling be reduced to every second year. Sampling of deep subtidal bedrock shores is no longer necessary; however, two new intertidal cobble monitoring sites are suggested.

1.0 Introduction

Monitoring the impact of the Cook Strait ferries on intertidal and shallow subtidal marine communities within Tory Channel and inner Queen Charlotte Sound began soon after fast ferries began operating between Wellington and Picton in the summer of 1994/95. Bedrock and cobble/boulder shores were monitored at impact sites along the Cook Strait ferry route and from distant reference sites in Tory Channel and Queen Charlotte Sound. The monitoring programme continued, with some modifications, during the period when fast ferries were operating at full operational speed (Davidson, 1995, 1996, 1997, 2000) and later when the fast ferries were required to slow down or after they had left service (Davidson 2002; Davidson and Richards, 2005; Davidson *et al*., 2010).

A Navigation Bylaw restricting fast ferries to a maximum speed of 18 knots was implemented on 15th December 2000 by the Marlborough District Council (MDC). 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 along the ferry route to recover from the impact generated by high speed ferries.

In response to this decision, additional data were collected immediately prior to the start of the Bylaw (Davidson, 2002). For the first time, quantitative data for reference 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).

Davidson (2002) reported on monitoring prior to and after the 18 knot Bylaw taking effect. Other reports were produced five years after the Bylaw (Davidson and Richards, 2005) and again at 10 years (Davidson *et al*., 2010). During the period between the initiation of the Bylaw (December 2000) and the Davidson and Richards (2005) report, high speed ferries ceased operation leaving only conventional ferries navigating through Tory Chanel and inner Queen Charlotte Sound (see Appendix 1).

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”.

Davidson *et al.* (2010) stated their study documented "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 reference sites, the only plausible explanation is a reduction in wave energy. At particular subtidal bedrock sites, the recovery surpassed reference 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 reference 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."

This current report updates the monitoring programme with new biological data collected between 2010 and 2017 (Table 1). The report concludes with comments on biological changes over the entire study period including before, during and after fast ferries were operating at unrestricted speeds.

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

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**	**2012**	**2013**	**2014**	**2016**	**2017**
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	5-Mar	5-Mar	3-Mar	8-Mar	
Time series (days)	0	142		212	237	258	275		310	357	625	688	791	890	1009	1513	1820	2092	1968	2274	2534	2828	3332	3640	4010	4405	4731	5084	5466	6208	6573	6936	7672	
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	5-Mar	5-Mar	3-Mar	8-Mar	
Time series (days)	0	159	206		247	268	285		320	367	635	698	801	900	1019	1523	1830	2102	1961	2284	2544	2838	3342	3650	4020	4415	4741	5094	5476	6218	6583	6946	7682	
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	5-Mar	5-Mar	3-Mar	8-Mar	
Time series (days)	0	21	54	75	95	116	133	155	168	215	483	546	649	748	867	1371	1678	1950	1947	2132	2392	2686	3190	3498	3868	4263	4589	4942	5324	6066	6431	6794	7530	
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	5-Mar	5-Mar	3-Mar	8-Mar	
Time series (days)						0	17		52	99	367	430	533	632	751	1255	1562	1834	1835	2016	2276	2570	3074	3382	3752	4147	4473	4826	5208	5950	6315	6678	7414	
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	5-Mar	5-Mar	3-Mar		23-Mar
Time series (days)																		0	18	182	442	736	1240	1548	1918	2313	2639	2992	3374	4116	4481	4844		5960
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	5-Mar	5-Mar	3-Mar		23-Mar
Time series (days)																		0	18	182	442	736	1240	1548	1918	2313	2639	2992	3374	4116	4481	4844		5960

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. Several 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 sub-ducting Pacific Plate, which is moving westwards beneath the Indian-Australian Plate at about 50 mm/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 10 m, 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 several 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.

Global sea levels have fluctuated by as much as 150 m 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 the 20th Century (Kirk and Newton, 1978). The modern and frequent inter-island ferry service using conventional ships started in 1962 and during the 1970’s 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 becoming 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 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.

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 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 Arahanga ceased operation in early 2001 and was replaced by Challenger (Kaitaki) in mid-2005. The Arahura retired from service in August 2015 and was replaced by the Stena Alegra (renamed Kaiarahi) from September 2015. Several 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 – June 2015). More recently Strait Shipping introduced the Strait Feronia in June 2015.

3.0 Methods

Using the same monitoring sites and methodology as (Davidson *et al*. (2010), data were collected on six additional occasions ending in March 2017. After the March 2014 sample, sampling of bedrock and cobble shores were alternated every second year with no sampling conducted in 2015.

Sampling comprised:

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

3.1 Cobble-small boulder shores

All cobble/small boulder reference sites were in Queen Charlotte Sound north-east of Dieffenbach Point. These areas of Queen Charlotte Sound are only occasionally used by ferries and large ships in certain circumstances (e.g. cruise-liners, safety reasons for inter-island ferries, and large ships steaming to and from Shakespeare Bay). 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 to low water), gently sloping in gradient, with the shallow subtidal often represented as an extension of intertidal habitats. Sites were spread widely to represent a large range of shore aspects and exposures to ferry and natural wave climates. Sites were located on shores with comparable topography and substratum to reduce variability.

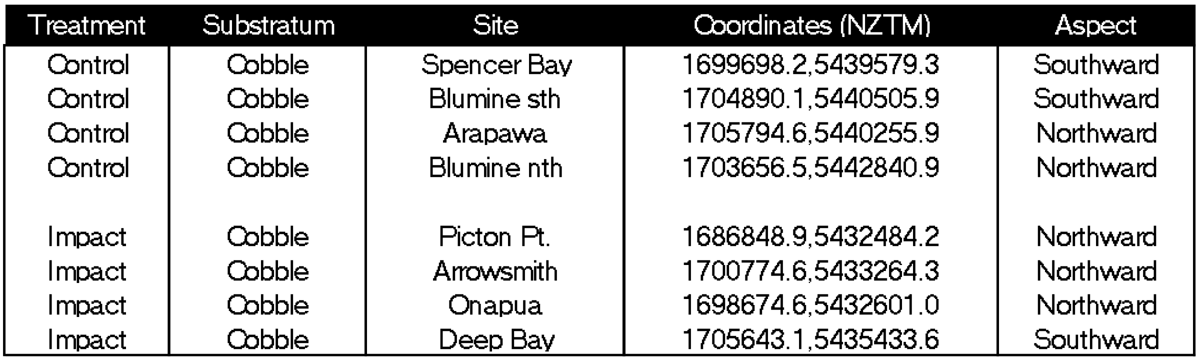
3.1.1 Intertidal cobble-small boulder (invertebrate density)

Apart from one impact site (Onapua: 2000 to 2016), all intertidal cobble-small boulder reference and impact sites were sampled between 1995 and 2016 (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 spring low water), 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 2016. Note: Onapua was sampled from 2000 to 2016.



Treatment	Substratum	Site	Coordinates (NZTM)	Aspect
Control	Cobble	Spencer Bay	1699698.2,5439579.3	Southward
Control	Cobble	Blumine sth	1704890.1,5440505.9	Southward
Control	Cobble	Arapawa	1705794.6,5440255.9	Northward
Control	Cobble	Blumine nth	1703656.5,5442840.9	Northward
Impact	Cobble	Picton Pt.	1686848.9,5432484.2	Northward
Impact	Cobble	Arrowsmith	1700774.6,5433264.3	Northward
Impact	Cobble	Onapua	1698674.6,5432601.0	Northward
Impact	Cobble	Deep Bay	1705643.1,5435433.6	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 impact sites and five reference sites (Figure 2, Table 3). Most sites were sampled from 1995 to 2017, apart from Spencer Bay and Blumine south (both 1997-2017) and Monkey Bay and Arrowsmith (both 2000-2016).

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 stakes driven into the substratum. On each sample occasion, either five or six haphazardly placed 10 x 1 m quadrats were sampled. Each 10 x 1 m quadrat was established by over-ending a 1 m^2 quadrat parallel to the shoreline. Within each individual 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 individual 1 m^2 predetermined and randomly assigned quadrats as a subset of the 50-60 total 1m^2 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 2016). Note: Spencer Bay and Blumine Island south were sampled from 1997 to 2016, while Monkey Bay and Arrowsmith were sampled from 2000 to 2016.

Treatment	Substratum	Site	Coordinates (NZTM)	Aspect
Control	Cobble	Double Bay	1700551.4,5437252.2	Northward
Control	Cobble	Spencer Bay	1699718.5,5439553.0	Eastward
Control	Cobble	Blumine sth	1704690.5,5440479.0	Southward
Control	Cobble	Clark Pt	1708423.7,5445283.7	Northward
Control	Cobble	Long Is	1706466.8,5446142.4	Northward
Impact	Cobble	Monkey Bay	1691603.8,5433692.6	Northward
Impact	Cobble	Dieffenbach west	1695187.0,5434335.4	Northward
Impact	Cobble	Arrowsmith	1700756.4,5433363.7	Northward
Impact	Cobble	Te Weuweu	1702176.1,5433090.4	Eastward
Impact	Cobble	Onapua	1698693.6,5432585.8	Eastward

3.1.3 Cast invertebrate presence-absence and density (intertidal)

Subtidal invertebrates recently cast onto the intertidal zone were counted from seven reference 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 reference sites were sampled from 1995 to 2016, excluding reference sites located at Snake Point and Blumine (north and south), sampled from 1997 to 2016. 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 60 cm 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 alongshore.

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 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 (1995-2016). Note: Blumine Island (north and south) and Spencer Bay were sampled 1997-2016.

Treatment	Substratum	Site	Coordinates (NZTM)	Aspect
Control	Cobble	Bay of Many Coves	1698482.1,5438857.8	Northward
Control	Cobble	Double Bay	1700517.9,5437245.3	Northward
Control	Cobble	Spencer Bay	1699694.1,5439588.7	Eastward
Control	Cobble	Blumine sth	1704732.2,5440524.0	Southward
Control	Cobble	Blumine nth	1703628.0,5442775.3	Northward
Control	Cobble	Clark Pt.	1708414.2,5445265.0	Northward
Control	Cobble	Long Is.	1706440.9,5446059.3	Northward
Impact	Cobble	Dieffenbach west	1695196.4,5434337.5	Northward
Impact	Cobble	Te Weuweu	1702192.9,5432966.9	Eastward
Impact	Cobble	Onapua	1698679.7,5432600.6	Eastward

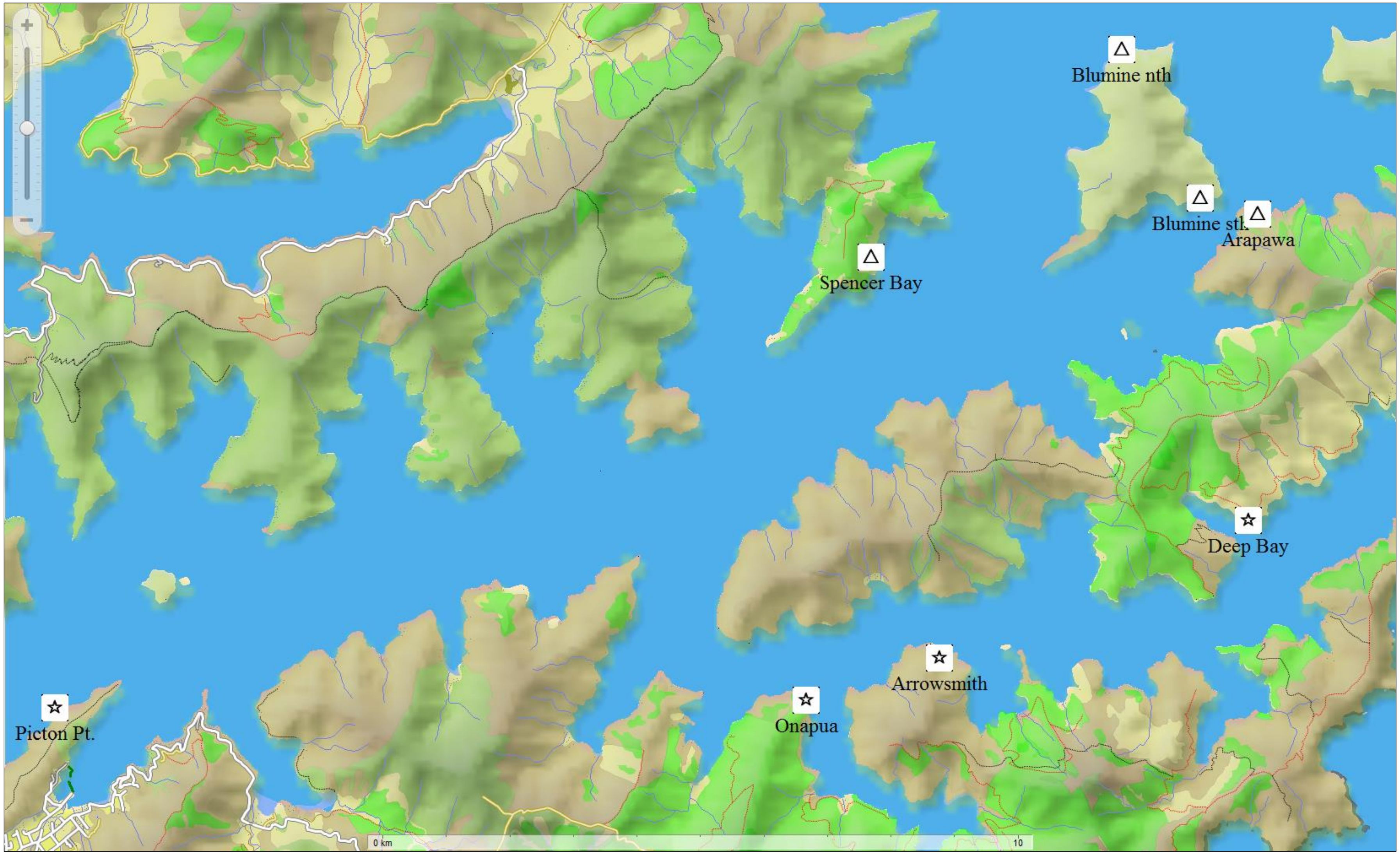


Figure 1. Location of intertidal cobble invertebrate sample sites. Reference = triangles, impact = stars.

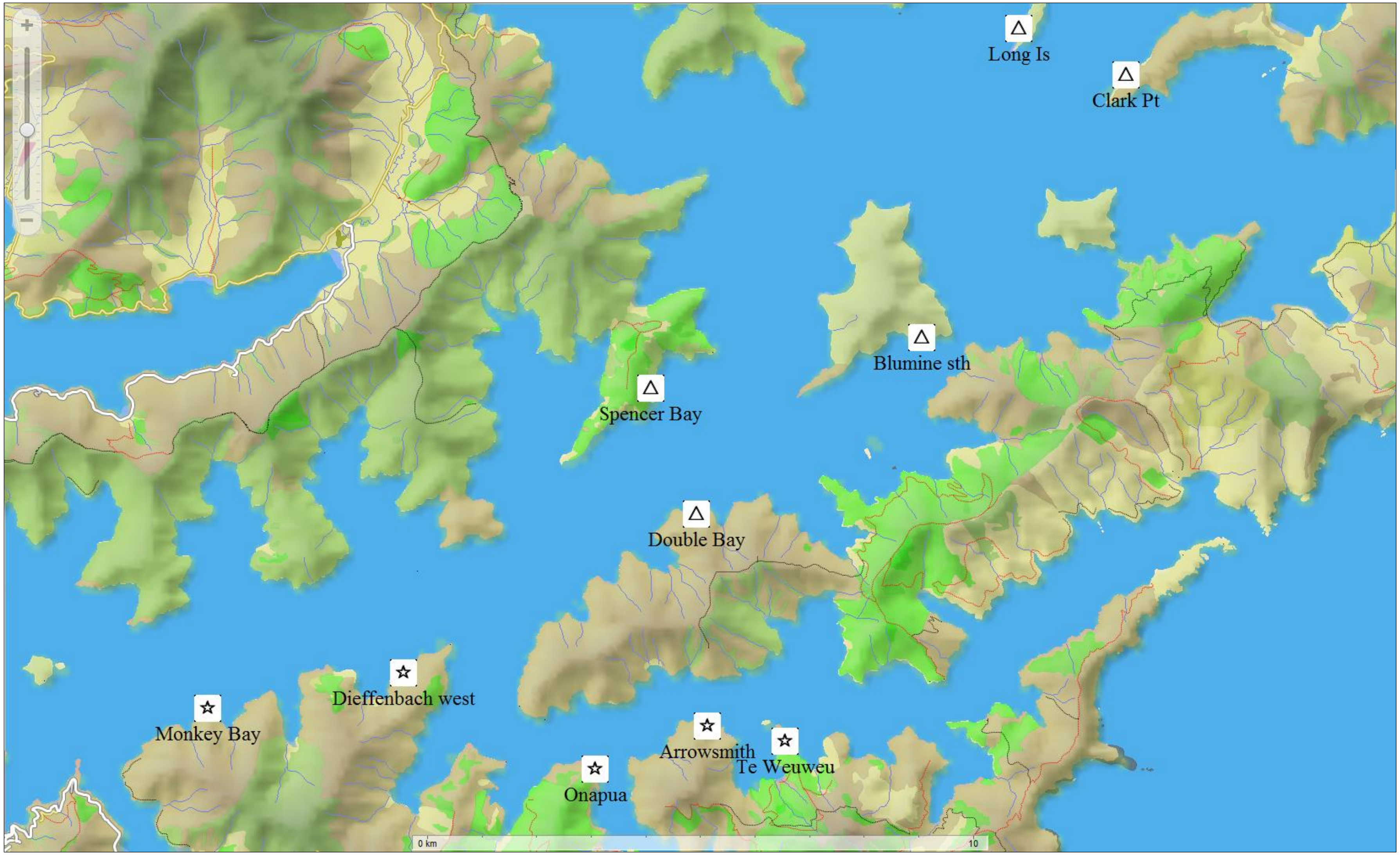


Figure 2. Location of subtidal cobble kina, cats-eye and black-foot paua sample sites. Reference = triangles, impact = stars.

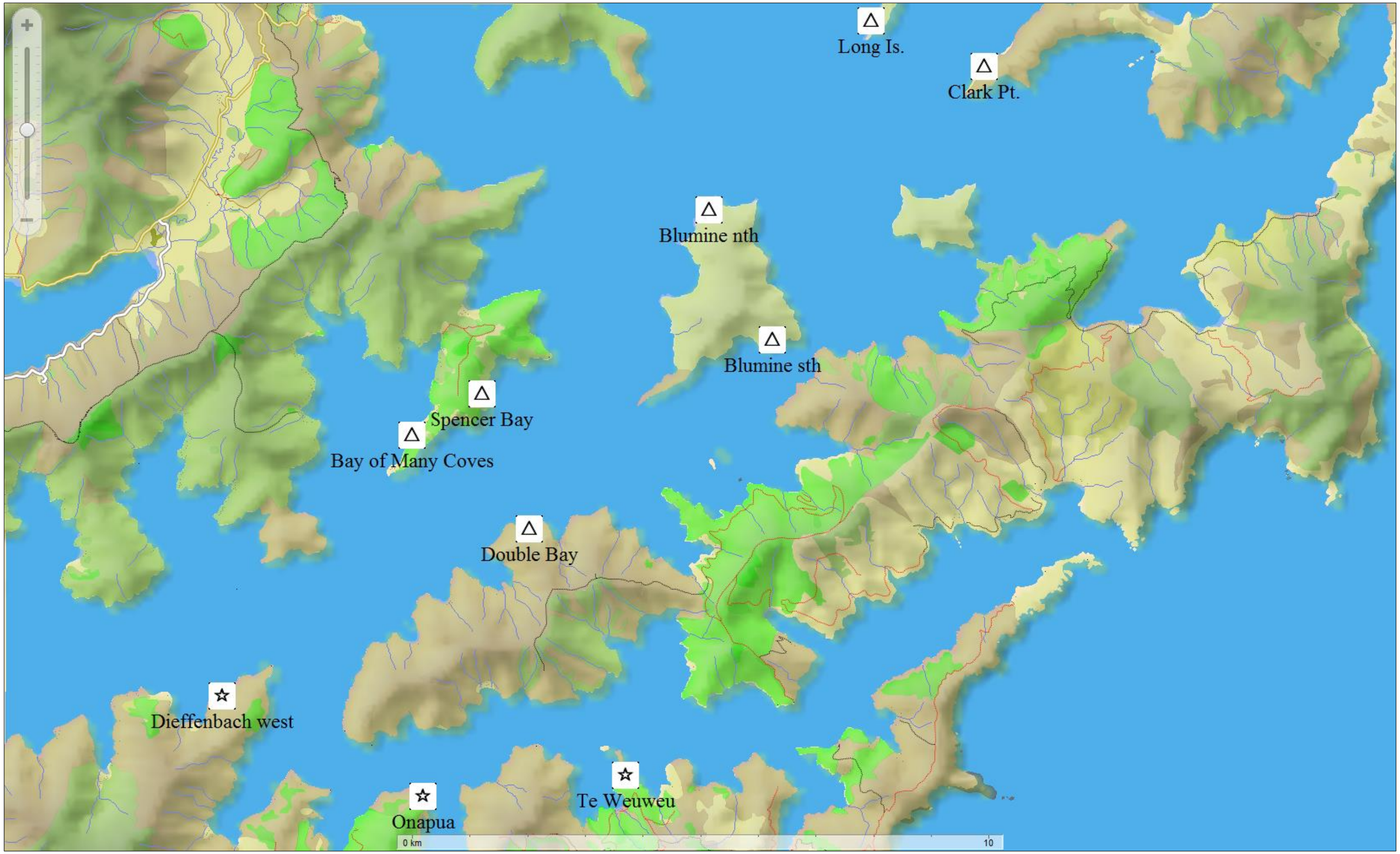


Figure 3. Location of intertidal cast invertebrate sample sites. Reference = triangles, impact = stars.

3.2 Bedrock shores

Apart from one bedrock reference site in inner Queen Charlotte Sound (Houhou Point), all reference sites were in Queen Charlotte Sound north-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 reference 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 reference and eight impact intertidal bedrock sites were sampled from inner and outer Queen Charlotte Sound and Tory Channel from 2000 to 2017 (Table 5, Figure 4). Bedrock shores were sampled on two occasions before and 15 occasions after the implementation of the 18-knot speed 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 spring low water). At each site, conspicuous "detachable" invertebrates were counted from 10 haphazardly deployed 1 m^2 quadrats. Only invertebrates that were easily detached from the substratum (e.g. topshells, whelks) were counted. Well-attached mollusc species (e.g. limpets, barnacles), which are unlikely to be dislodged by ferry generated waves, were not sampled.

3.2.2 Subtidal bedrock (invertebrate density)

A total of five reference and six impact subtidal bedrock sites were sampled using SCUBA 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, top-shells, rock shells, whelks, 11 arm sea-star, urchins, cushion sea-stars, paua, and sea cucumber.

Table 5. Intertidal bedrock sites in Tory Channel and Queen Charlotte Sound (2000 - 2017).

Treatment	Substratum	Site	Coordinates (NZTM)	Aspect
Control	Bedrock	Houhou Pt.	1681240.2,5432518.2	Southward
Control	Bedrock	Snake Pt.	1698151.6,5438346.9	Northward
Control	Bedrock	Double Bay	1700757.6,5437378.9	Northward
Control	Bedrock	Umuwheke Pt.	1701849.2,5437642.4	Northward
Control	Bedrock	KuraKura Pt.	1700474.2,5440100.0	Southward
Control	Bedrock	Blumine (south)	1704933.2,5440510.8	Southward
Impact	Bedrock	Allports Is.	1688529.3,5434149.2	Southward
Impact	Bedrock	Golden Pt.	1690314.3,5435267.4	Northward
Impact	Bedrock	Monkey Bay	1691670.3,5433683.6	Northward
Impact	Bedrock	Kahikatea Bay	1693778.0,5434504.8	Northward
Impact	Bedrock	Ruaomoko Pt.	1697436.5,5433602.2	Westward
Impact	Bedrock	Arrowsmith Bay	1700693.7,5433484.1	North-eastward
Impact	Bedrock	Ngaruru Bay	1703206.6,5434308.8	Southward
Impact	Bedrock	Tory Channel	1704919.2,5434192.8	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 10 to 20 x 1 m^2 quadrats. Contiguous quadrats were installed by over-ending a 1 m^2 quadrat. Macroinvertebrates selected for investigation were large species that were often present at subtidal sites, but were patchily distributed; i.e. 11 arm sea-star (*Coscinasterias muricata*), kina or urchin (*Evechinus chloroticus*), and sea cucumber (*Stichopus mollis*). These species were also sampled using the first method outlined above to provide a comparison.

Table 6. Subtidal bedrock sites in Tory Channel and Queen Charlotte Sound (2000 - 2017).

Treatment	Substratum	Site	Coordinates (NZTM)	Aspect
Control	Bedrock	Houhou Pt.	1681234.5,5432502.7	Southward
Control	Bedrock	Snake Pt.	1698108.8,5438355.8	Northward
Control	Bedrock	Double Bay	1700776.6,5437381.1	Northward
Control	Bedrock	Umuwheke Pt.	1701858.4,5437648.8	Northward
Control	Bedrock	KuraKura Pt.	1700462.8,5440076.3	Southward
Impact	Bedrock	Allports Is.	1688529.7,5434138.7	Southward
Impact	Bedrock	Golden Pt.	1690276.9,5435235.4	Northward
Impact	Bedrock	Monkey Bay	1691702.3,5433688.2	Northward
Impact	Bedrock	Kahikatea Bay	1693774.7,5434508.7	Northward
Impact	Bedrock	Arrowsmith Bay	1700750.1,5433447.0	North-eastward
Impact	Bedrock	Ngaruru Bay	1703203.8,5434301.3	Southward

Figure 4. Location of intertidal bedrock sample sites. Reference = triangles, impact = stars.

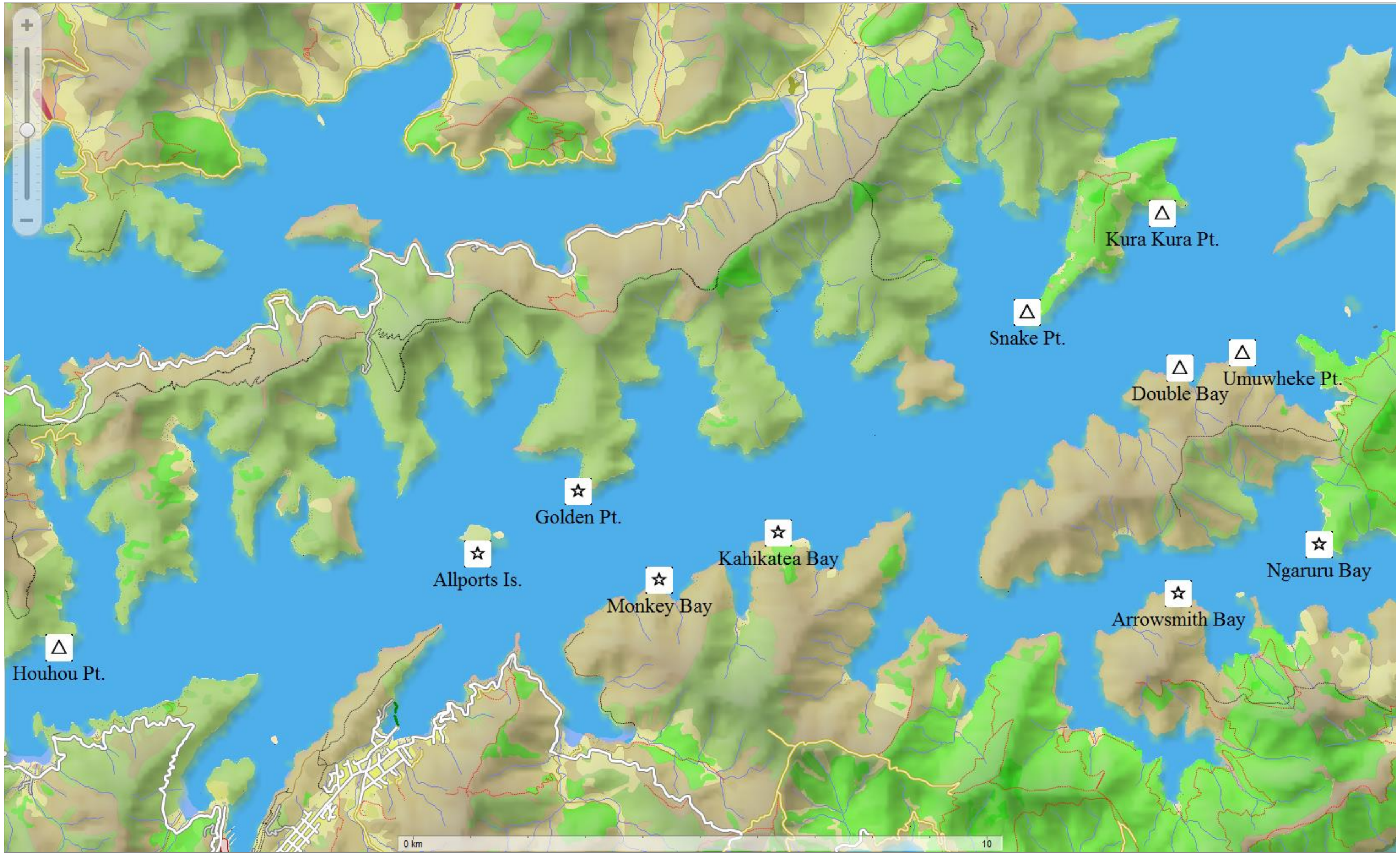


Figure 5. Location of subtidal bedrock sample sites. Reference = triangles, impact = stars.

3.3 Statistical analysis

Pooled means were compared between reference and impact treatments on each sample occasion using a t-test run in Sigmplot 12.5. Data collected from individual sites were not compared statistically. The t-test asks whether a difference between two groups' averages is unlikely to have occurred because of random chance. A difference is more likely to be statistically significant if:

(1) the difference between the averages is large;
(2) the sample size is large; and
(3) measured variability (e.g. standard deviation) is low.

On some occasions, the normality test (Shapiro-Wilk) failed and a Mann-Whitney Rank Sum Test was applied to the means.

Regression lines were fitted to the pooled mean values for each sample occasion in Sigmaplot 12.5 for: (a) reference, (b) pre-Bylaw impact (where applicable), and (c) post Bylaw impact treatments. X-axis data were standardised to a numerical sequence rather than using sample dates. The analysis generated p-values for each line, with $p \leq 0.05$ indicating the data had a good fit to the regression line whereas $p > 0.05$ indicating there was a poor fit.

Regression coefficients or line slopes coefficients represents the mean change in the response variable for one unit of change in the predictor variable while holding other predictors in the model constant. The coefficient indicates, for every additional sample event, whether an increase or decrease (e.g. in mean density or number of species) would be expected to occur.

Regression analysis was complicated for some metrics and locations due to significant variation in the data or because of a non-linear relationship between time (x-axis) and the response variable (y-axis); e.g. where the rate of change levels out over time to reach a new "equilibrium" state. No transformations were applied to the data to account for non-linear relationships.

4.0 Results

4.1 Intertidal cobble-small boulder shores

4.1.1 Number of macroinvertebrate species (intertidal cobble-boulder)

For reference sites, the mean number of invertebrate species living on and under cobbles usually ranged from 4 to 12 (mid tide) and 7 to 12 species (low tide) over the 21-year study (Figures 6 and 7). Occasionally, the mean number of species breached these ranges (e.g. Spencer Bay low tide in May 2001. No pattern of change occurred at mid or low tide reference sites following the introduction of the Bylaw.

At impact sites, the mean number of species at both tidal levels ranged between 0 and 8 species (Figures 6 and 7). At both tidal heights, three of the four impact sites exhibited an increase following the introduction of 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 towards the lower values recorded at reference sites.

At both tidal heights, the mean number of species from pooled reference sites was consistently higher compared to the pooled impact treatment ($T= 378$, $P <0.001$) (Figures 6 and 7). Over the duration of the study the mean number of species at both reference tidal heights declined to a small degree; however, only the low tide regression line was a good fit (mid-tide regression slope =-1.75, r^2 = 1.97%, $P = 0.46$; low-tide regression slope = -7.04, r^2 =43.6%, $P <0.001$).

For impact sites, the mean number of species declined at both tidal heights to low points immediately prior to the Bylaw (mid-tide regression slope =-1.138, r^2 = 4.86%, $P = 0.49$; low-tide regression slope = -2.38, r^2 =31%, $P = 0.06$). Following the introduction of the speed restriction, the pooled mean number of species at impact sites increased towards the reference treatment levels (mid-tide regression slope =3.05, r^2 = 41.1%, $P = 0.004$; low-tide regression slope =3.47, r^2 =68.6%, $P <0.001$).

4.1.2 Mollusc density (intertidal cobble-boulder)

The mean density of intertidal molluscs at reference sites most often ranged from 15 to 45 individuals per rock at mid tide and 10 to 35 individuals per rock at low tide (Figures 8 and 9).

Occasional mean values for reference sites breached above and below these ranges (e.g. Blumine Island south at low tide in May 1997). No obvious changes to individual reference site values occurred relative to the Navigational Bylaw.

At impact sites, the mean density of molluscs at mid and low tide was usually lower compared to reference sites ($t = -18.84$, $P < 0.001$ mid-tide; $T = 379$, $P < 0.001$ low-tide) (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 (e.g. Arrowsmith and Picton Point). Apart from Picton Point, the density of molluscs increased at both tidal heights after the introduction of the Navigational Bylaw (Figures 8 and 9). The scale of this increase was initially modest and variable between sites, with the greatest increases recorded at mid tidal levels at Deep Bay (Figure 8).

The mean density of mid tide molluscs from the pooled reference treatment remained higher than the pooled impact treatment over the duration of the (Figure 8). Mean values were variable between years but usually remained within a distinct density range. Overall, mean values at mid tide ended close to where they started but the nearly flat (slightly negative regression line) had a poor fit (slope = -0.113, r^2 = 0.3%, P = 0.78). At low tide, mean values declined over the study (slope = -0.67, r^2 = 29.7%, P = 0.002) (Figure 9).

Prior to the By-law, impact densities fluctuated little (as indicated by a flat regression line) at mid-tide sites (slope = 0.173, r^2 = 0.6%, P = 0.81), however, the regression line fit was very poor. Impact mid-tide mollusc densities increased following the introduction of the Bylaw, peaking in February 2005 and again in March 2013 (regression slope =0.71, r^2 = 54.7%, P = 0.002). By March 2013, mean mid-tide impact densities approached densities recorded at the pooled reference treatment. The mid-tide peak in 2013 was short lived with densities declining steeply from 2014 to 2016 (Figure 8).

Smaller peaks in mollusc densities were recorded at the low tide impact sites in 2005 and 2013 (Figure 9). There was also a decline in mollusc densities at these stations at the end of the study, but less pronounced than the drop recorded at the mid tidal level.

Mean densities of molluscs declined prior to the Bylaw at low tide impact and reference cobble sites (slope = -0.97, r^2 = 32.8%, P = 0.052). The increase in mollusc density recorded after the Bylaw at the low tide pooled impact treatment followed a similar trend to that at the mid-tide level, but on a smaller scale with data being a poor fit to the line (slope = 0.72,

r^2 = 19.6%, P = 0.099) (Figure 9). Again, densities at the impact pooled treatment came close to pooled reference treatment values in some years (e.g. February 2005 and March 2013) (Figure 9). This was compounded by a continuing decline in mean densities at the pooled refence treatment before and after the by-law.

4.1.3 Cast invertebrates (intertidal cobble-boulder)

The number of invertebrate species washed ashore at reference sites varied little over the duration of the study with most values falling between 0 to 4 species per site (Figure 10). On three occasions, 3 or 4 species were recorded at a reference site (Double Bay).

After February 2005, a low number of cast species were recorded at impact sites (0-2 species). Prior to 2005, 3-5 species of cast animals were regularly recorded and a peak of 11 species was recorded at Dieffenbach in January 1996.

Pooled number of species values showed a similar pattern with the reference treatment remaining relatively low for the study duration. The impact treatment showed a greater variation with highest values recorded in the first few years, particularly in January 1996, 1997, February 2000 and December 2002 compared to reference sites (Figure 10).

The mean abundance of cast invertebrates from both reference and impact treatments remained relatively low for most of the study (Figure 11). Dieffenbach Point was the exception, with a peak in January 1996 and smaller peaks in February 2000 and December 2002. For the pooled reference treatment, the mean number of cast invertebrates remained relatively low both before and after the Bylaw, compared to the impact treatment where elevated numbers were recorded before and on three occasions after the speed restriction (Figure 11).

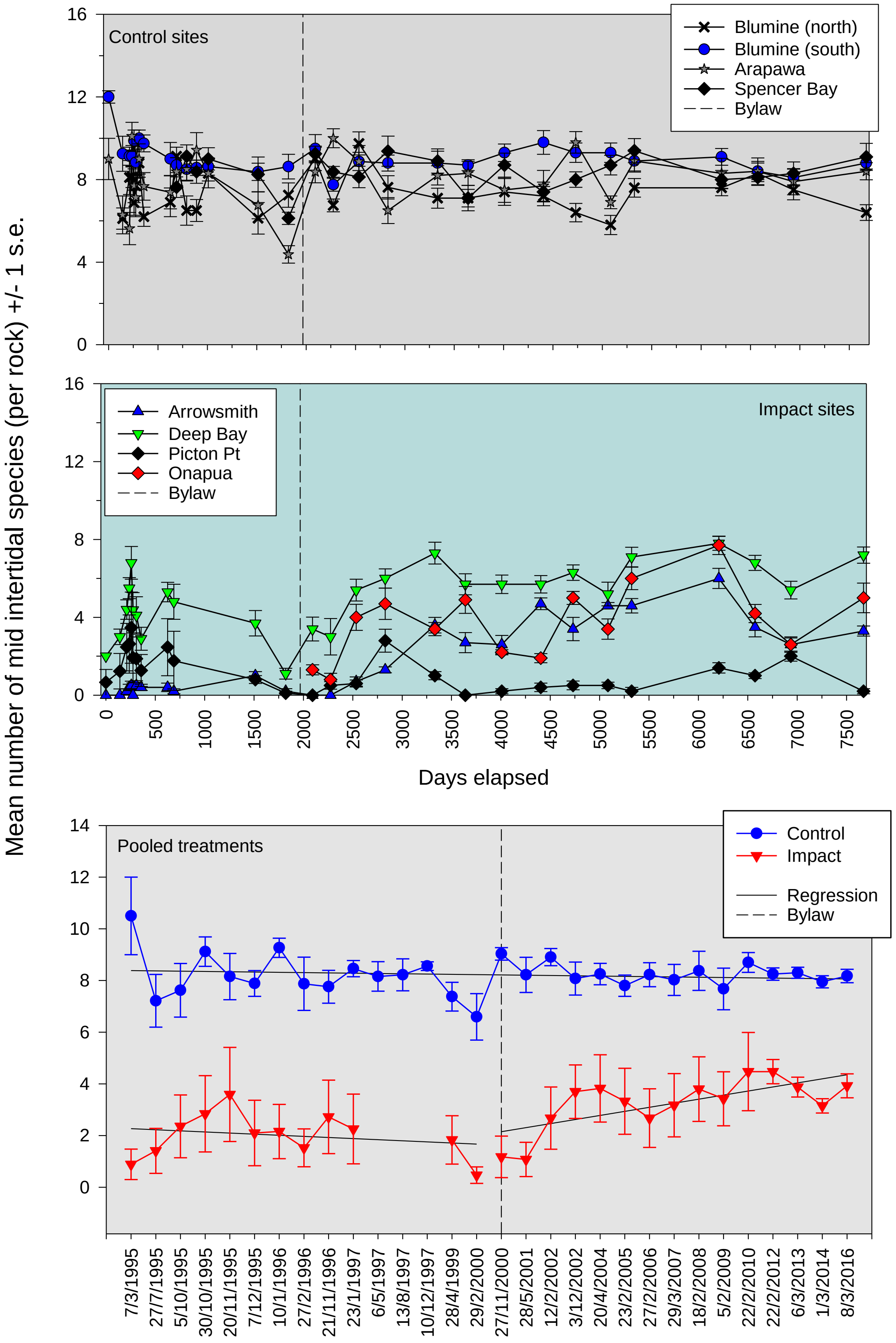


Figure 6. Mean number of invertebrate species recorded from mid tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to March 2016) ($^{+}$/- 1 S.E.).

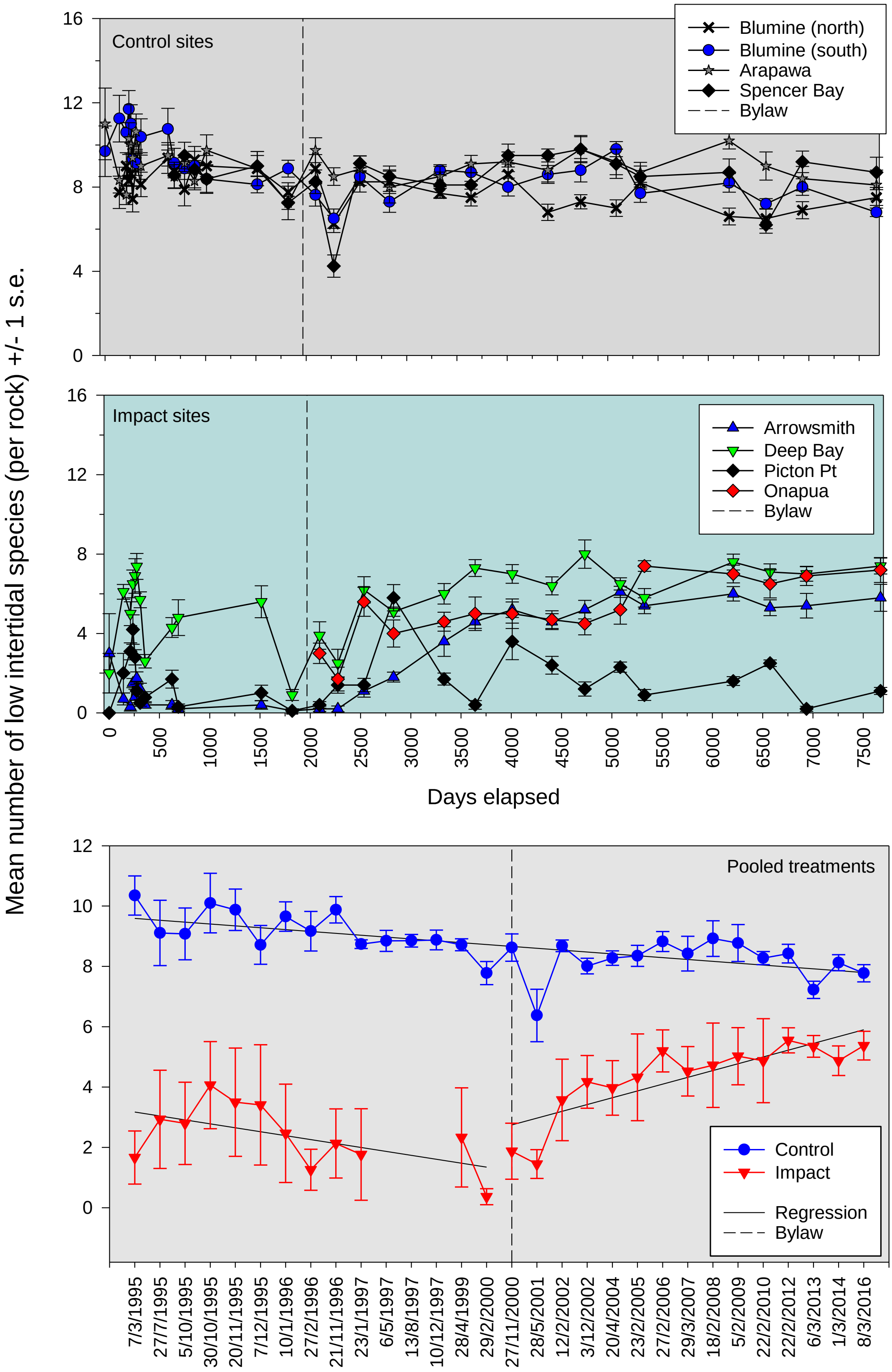


Figure 7. Mean number of invertebrate species recorded from low tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to March 2016) ($^+$/- 1 S.E.).

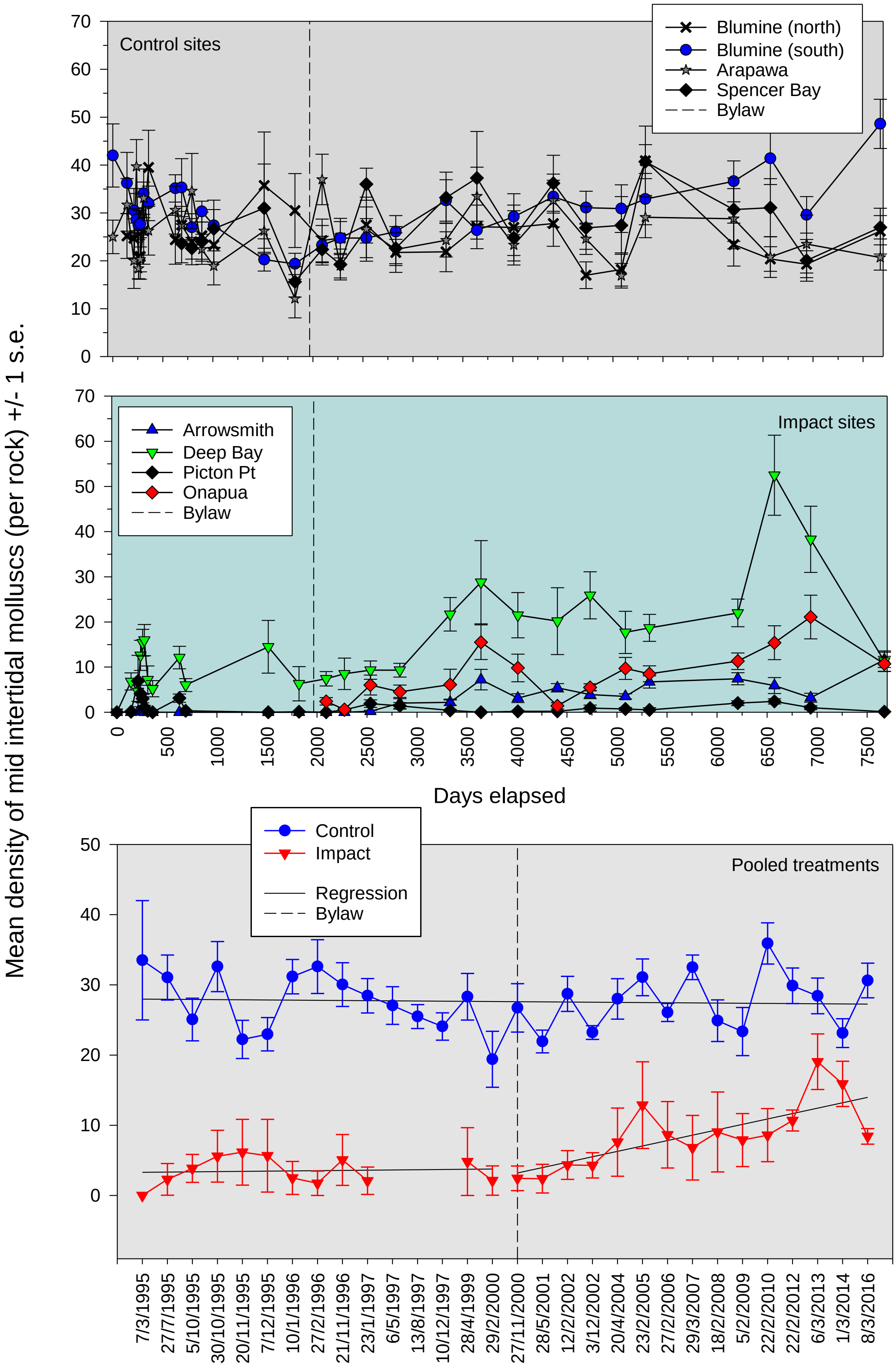


Figure 8. Mean density of individual molluscs recorded from mid tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to March 2016) (+/- 1 S.E.).

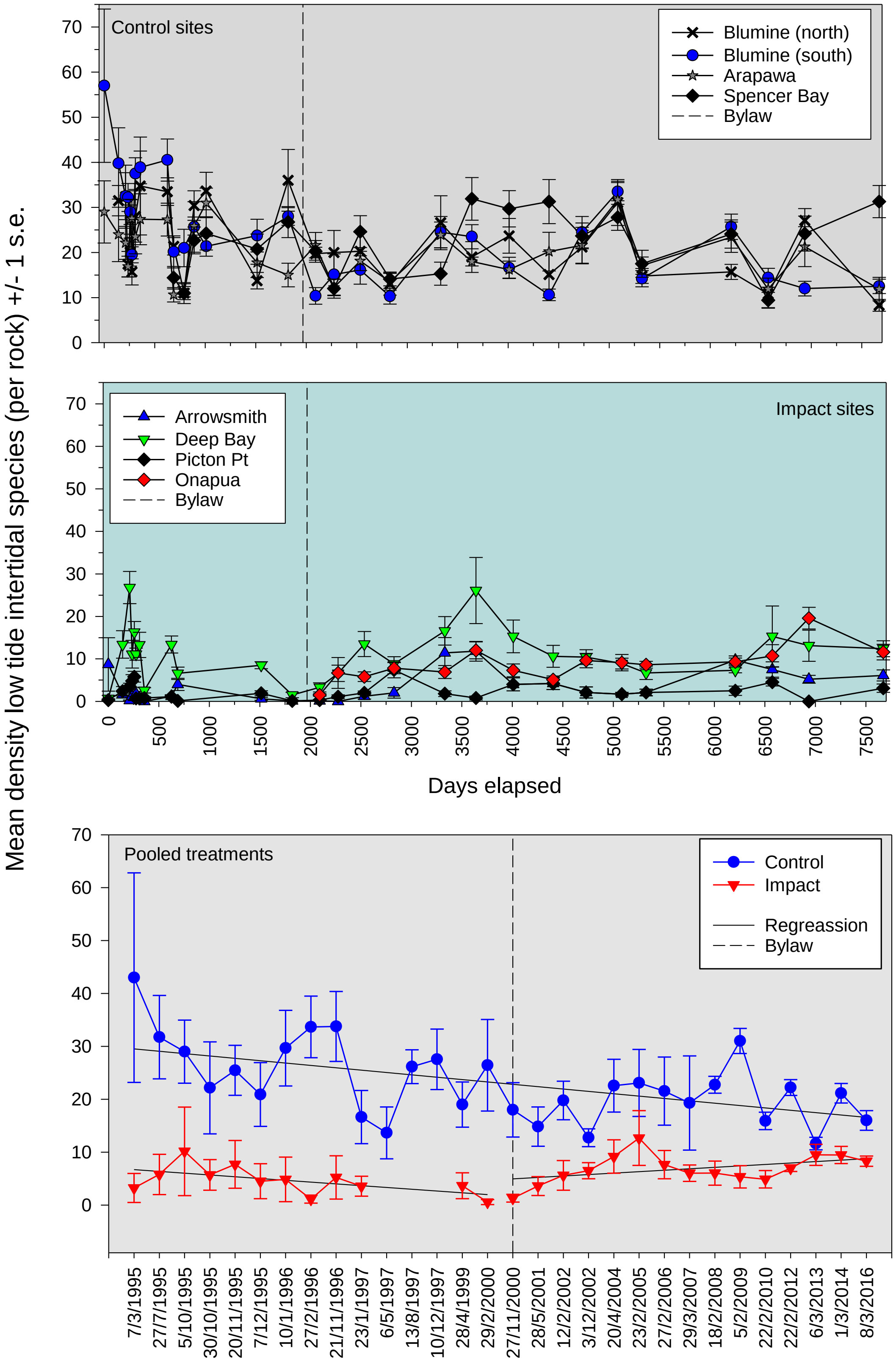


Figure 9. Mean density of individual molluscs recorded from low tide cobbles and small boulders, Queen Charlotte Sound and Tory Channel (March 1995 to March 2016) (+/- 1 S.E.).

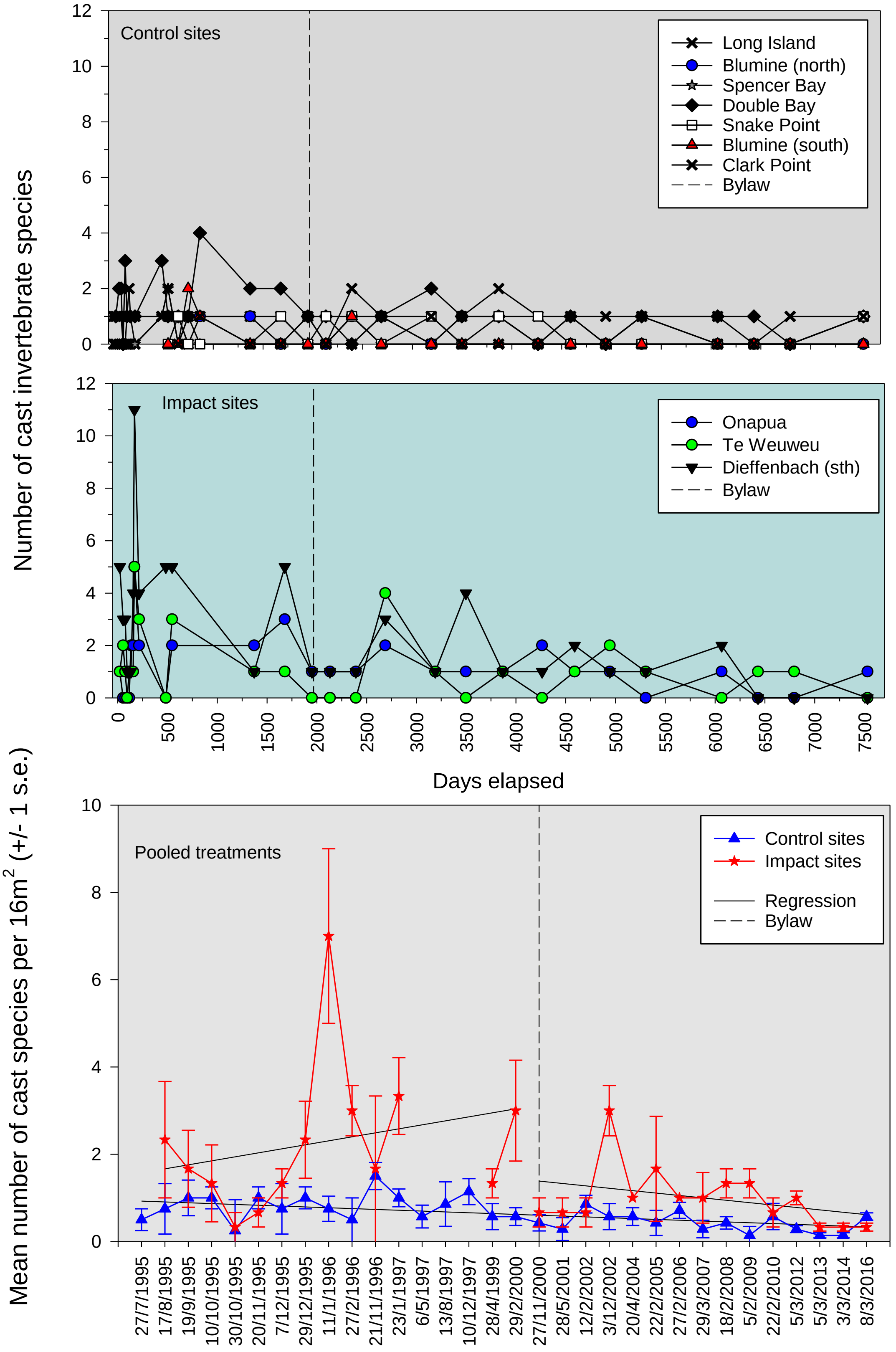


Figure 10. Number of species recorded from cast animal quadrats sampled at reference and impact sites and from mean pooled treatments from July 1995 to March 2016 ($^{+}$/- 1 S.E.).

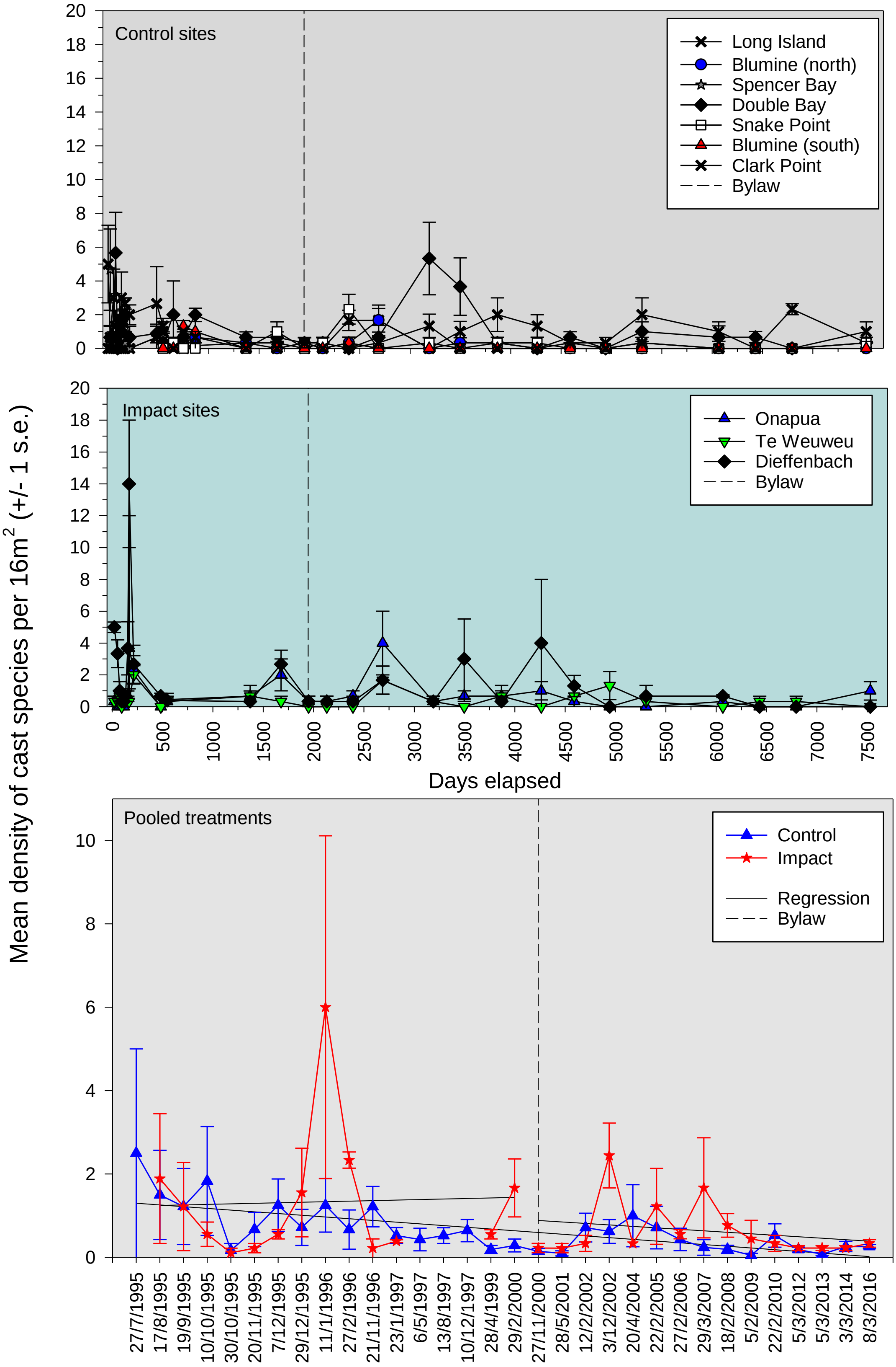


Figure 11. Mean density of individuals of all species recorded from cast animal quadrats sampled at pooled reference and impact sites from July 1995 to March 2016 ($^{+}$/- 1 S.E.).

4.2 Subtidal cobble-small boulder

4.2.1 Kina (subtidal cobble-boulder)

Kina (*Evechinus chloroticus*) density varied between the five reference sites with two sites (Long Island and Clark Point) regularly supporting higher urchin numbers (Figure 12). Kina densities ranged from 0.5 to 16 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. The exception was Clark Point where a large range between peaks and lows occurred (Figure 12).

Prior to the Bylaw, urchins (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 and Arrowsmith remained at comparable levels before and after the speed restriction.

Although high variability recorded between the five reference sites resulted in relatively large error bars associated with pooled means, significantly higher densities were recorded from the reference treatment compared to the impact sites ($t = -8.413$, $P < 0.001$) (Figure 12). Kina density for the reference treatment also fluctuated between sample events throughout the study, with peaks in 1995, February 2002, April 2004, March 2007 and March 2012. Lowest values (<2.5 individuals per m^2) for the reference treatment were recorded in December 2002 and February 2009 (Figure 12). The regression line was flat and slightly negative (regression reference slope = -1.04, r^2 = 1.1%, P = 0.59), but the fit was poor. Overall, pooled reference means ended very close to where they started.

Kina densities at the pooled impact treatment initially declined from 1995 and 1996 to a low in November 2000 (negative regression slope = -3.94, r^2 = 22.6%, P <0.12). Up to December 2002, impact density was well below the pooled reference treatment value. Four years after the Bylaw was implemented, kina numbers increased (regression slope = 2.03, r^2 = 28.6%, P = 0.04) at the impact treatment to levels near, but below, the reference treatment (Figure 12).

Impact pooled means increased after the Bylaw's introduction (positive regression slope = 0.000345, r^2 = 27.1%, P = 0.047), with kina densities at the impact treatment peaking in February 2006 and March 2013 (Figure 12).

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

At reference sites, mean cats-eye (*Turbo smaragdus*) density remained relatively consistent within individual sites with means ranging from 0 to 12 individuals per m^2 (Figure 13). Densities were consistently lowest from the most north-eastern reference sites located at Long Island and Clark Point, while Spencer Bay usually supported the highest densities.

At impact sites, densities varied both within and between sites over the study (Figure 13). Densities were highest in the first year of the study at the three sites surveyed at that time. This was followed by a period where densities declined. Following the introduction of the Bylaw, the abundance of snails increased at four of the five impact sites (note: two additional sites were added immediately prior to the bylaw). Largest increases occurred at Onapua, Arrowsmith and Monkey Bay.

Cats-eye densities from the pooled reference treatment increased gradually over the duration of the study (regression slope = 3.59, r^2 = 20.8%, P = 0.019). Small lows were recorded in November 1995, 1996, May 2001 and March 2016 (Figure 13).

In contrast, pooled cats-eye density at the impact sites prior to the Bylaw declined from approximately 17 individuals per m^2 in 1995 to <3 individuals per m^2 (negative regression slope = -0.53, r^2 = 61.9%, P= 0.021). Overall, cats-eye snails were more abundant from the pooled impact treatment (T = 794, P <0.001). Pooled cats-eye density at the impact sites increased above the reference treatment two years after the Bylaw came into effect and continued to increase for several more years (positive regression slope = 1.52, r^2 = 61%, P< 0.001) (Figure 13).

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

Black-foot paua (*Haliotis iris*) were almost always present at Clark Point, but were absent or uncommon at the four other reference sites (Figure 14). At Clark Point, paua varied from 0 to 1.7 individuals per m^2 and were almost always observed in depths less than 1 m immediately below the low water mark.

At impact sites, paua density remained low throughout the study and showed no apparent change in relation to the Bylaw. Paua were recorded from all five impact sites, but always at densities <0.4 individuals per m^2. Highest densities of paua were recorded at Te Weuweu Bay and Arrowsmith (Figure 14).

The pooled density of paua for the reference treatment largely reflected the pattern in abundance recorded from Clark Point. For the impact treatment, the greatest variation in paua density occurred in the first 2-3 years of the study followed by a stable period of low paua density from August 1997 to March 2016 (Figure 14). Overall paua densities from the two treatments were not significantly different (T = 661, P = 0.052).

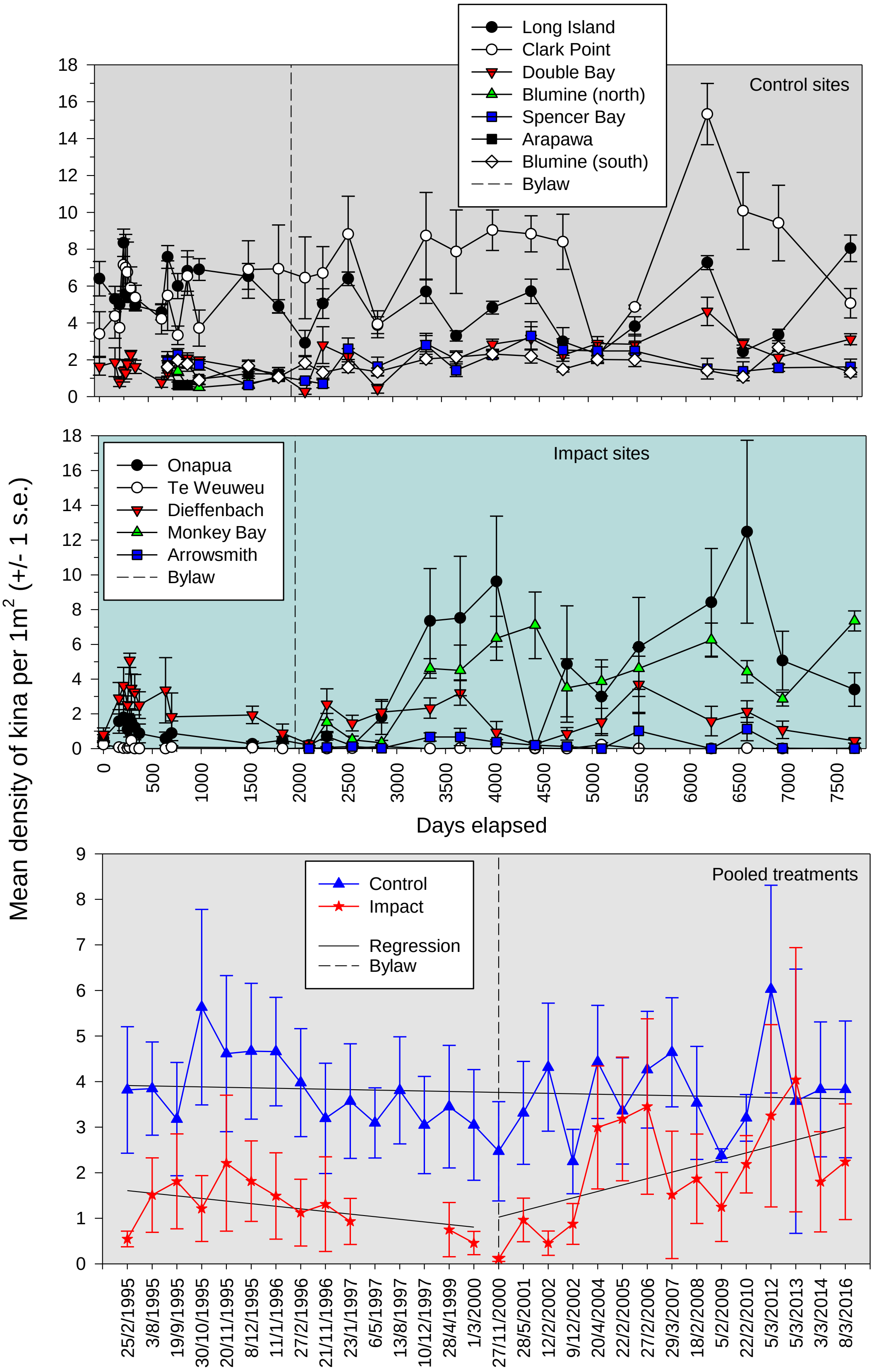


Figure 12. Mean density of kina recorded from shallow subtidal cobbles and small boulders in Queen Charlotte Sound and Tory Channel from March 1995 to March 2016 ($^+$/- 1 S.E.).

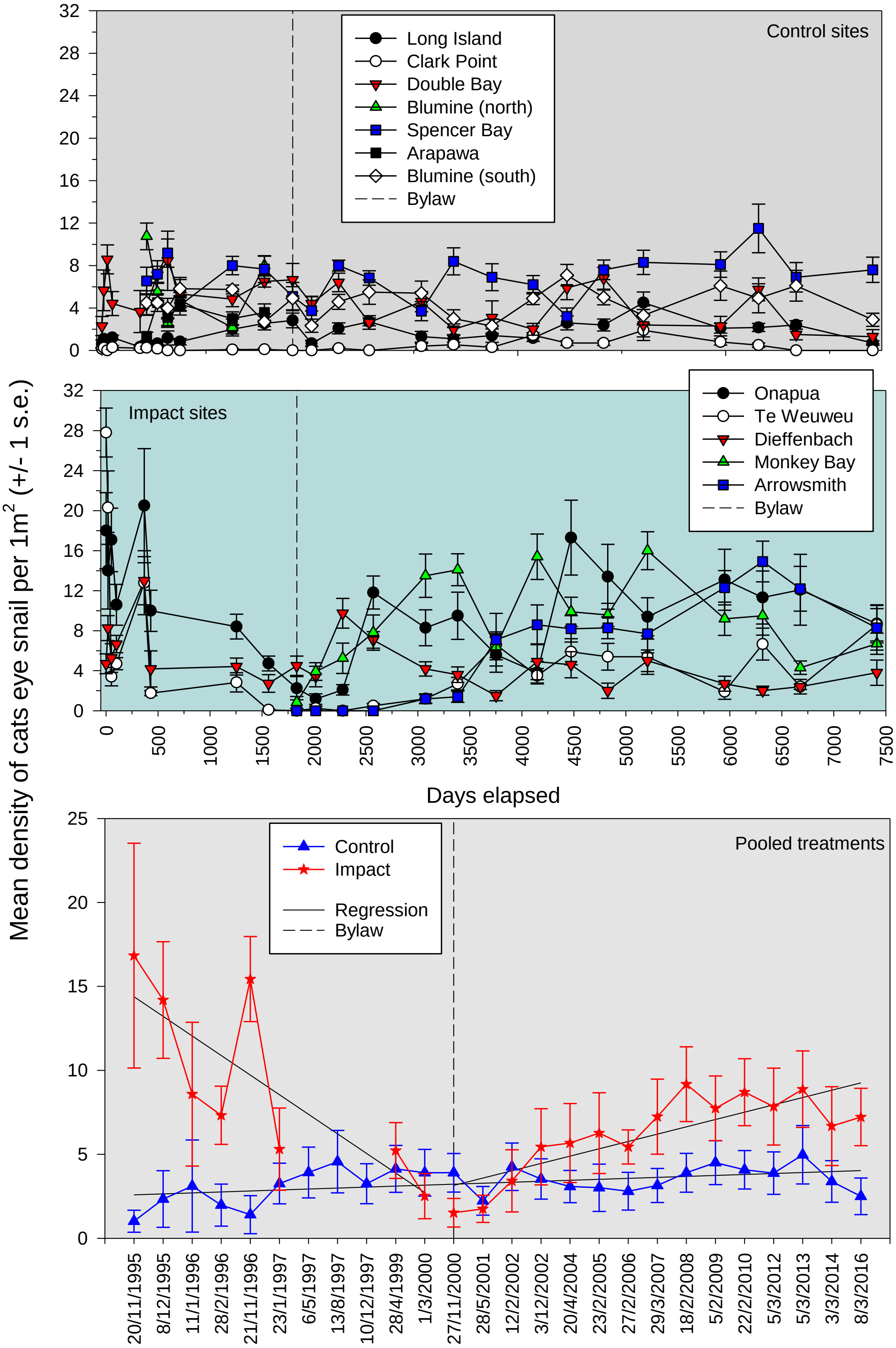


Figure 13. Mean density of cats-eye snails recorded from shallow subtidal cobbles and boulders in Queen Charlotte Sound and Tory Channel from March 1995 to March 2016 2016 ($^+$/- 1 S.E.).

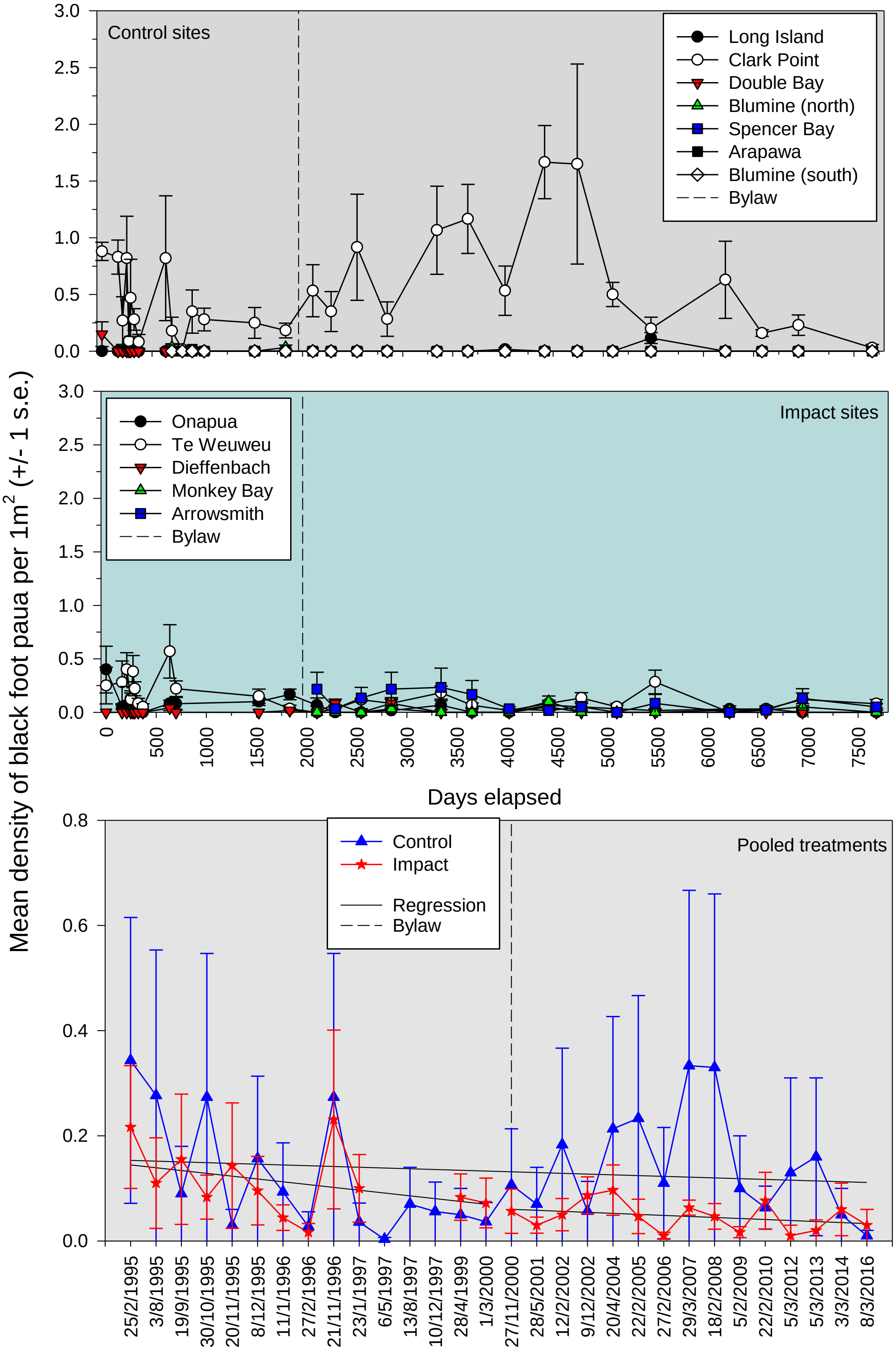


Figure 14. Mean density of black-foot paua recorded from shallow subtidal cobbles and boulders in Queen Charlotte Sound and Tory Channel (March 1995 to March 2016) ($^{+}$/- 1 S.E.).

4.3 Intertidal bedrock

4.3.1 Mobile molluscs (intertidal bedrock)

Number of species

The number of detachable or "mobile" mollusc species at intertidal bedrock reference sites ranged from 3 to 8 compared to 1 to 7 at impact sites (Figure 15). Both impact sites with near vertical walls (Tory and Ngaruru) supported the lowest number of species (i.e. 1 to 5). In comparison, 5 to 8 species were recorded from steep gradient reference sites.

The pooled number of intertidal bedrock species was higher at the reference treatment compared to impact treatment ($t = -4.09$, $P < 0.001$). This difference was most apparent during the first two years, but reduced thereafter (Figure 15), primarily due to a steeper decline for the mean number of species at reference sites compared to the impact treatment (regression slope reference = -4.71, $r^2 = 74.1$, $P < 0.001$; regression slope impact = -3.9, $r^2 = 25.6$, $P = 0.054$). The mean number of species at the impact treatment declined to an all-time low in February 2010, but subsequently recovered to be near the reference treatment level in 2017 (Figure 15).

Mobile mollusc density

The density of mobile molluscs at reference sites ranged from 6.8 to 105.2 individuals per m^2, while 0.1 to 59.2 individuals per m^2 were counted at impact sites (Figure 16). At Double Bay, Umuwheke and Snake Point, the density of mobile molluscs fluctuated for some years, whereas mollusc densities remained relatively stable at other reference 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 initially increased at most sites, but remained low at Arrowsmith, Tory, and Ngaruru (Figure 16). Impacts sites at Monkey Bay, Kahikatea, Ruaomoko and Golden Point supported densities comparable to low density reference sites, while Tory and Ngaruru supported low mobile mollusc densities throughout the study.

Mobile mollusc densities from the pooled reference treatment declined slightly (regression slope = -0.056, $r^2 = 3.2$, P = 0.74); however, the regression line was a poor fit. Reference values were higher compared to the impact treatment (t = -12.18, P< 0.001). Despite low densities recorded at Ngaruru and Tory, the pooled mean density of mobile molluscs for the impact treatment steadily increased after the Bylaw was introduced (regression slope = 0.42, r^2 = 18.8%, P =0.11), peaking in February 2006 and again in March 2014 (Figure 16). The fit of the impact regression line was, however, poor.

4.3.2 Cats-eye snail (intertidal bedrock)

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

Cats-eye densities initially increased for the pooled impact treatment following the Bylaw's introduction to a high in April 2004 (Figure 17). This peak in abundance was followed by a decline to February 2008, a subsequent increase to a second smaller peak in February 2009, followed by a further decline. Notwithstanding these fluctuations, there appears to be a general pattern of increasing cats-eye density for impact sites for the first four years following the bylaw, followed by an overall decline after 2004.

Pooled reference site data showed differences and some similarities to this pattern (Figure 17). Both treatments followed a very similar pattern after 2004 and especially 2007.

Overall, reference mean pooled densities finished lower than at the start of the study, whereas impact pooled means finished at a level close to the start of the study, but still well below most sample events. Despite these fluctuations and differences, overall there was no significant difference between the pooled means for each treatment over the duration of the study (T = 229, P = 0.901).

4.3.3 Topshell (intertidal bedrock)

The mean density of topshell (*Melagraphia (Diloma) aethiops*) from intertidal bedrock reference 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 several peaks and troughs (Figure 18).

Mean topshell density at impact sites ranged from 0 to 27 individuals per m^2. Apart from a small increase in February 2005 at Kahikatea and in February 2006 at Ruaomoko, and both sites in March 2014, the density of topshells remained low at most impact sites over the duration of the study.

Pooled mean topshell density was always higher at the reference treatment compared to the impact treatment ($T = 345$, $P < 0.001$) (Figure 18). Topshell abundance at impact sites increased gradually after the introduction of the Bylaw, peaking in February 2006. Topshell density declined to lower levels following this initial peak, before recovering slightly in March 2014 and declining again in March 2017.

In the pooled reference treatment, topshell densities also increased after the Bylaw peaking in December 2002, followed by an overall decline through to February 2009. Two further peaks in abundance occurred in March 2012 and March 2014. By the end of the study, topshell abundance at the pooled reference treatment returned to levels close to those recorded at the start of the study (Figure 18).

4.3.4 Oyster borer (intertidal bedrock)

Mean abundance of oyster borer (*Lepsiella scobina*) ranged from 0 to approximately 62 individuals per m^2 at reference sites compared to 0 to 38 individuals per m^2 at impact sites. At reference sites, apart from Umuwheke, Snake Point 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 with two major peaks in 2001 and 2012. One peak in abundance occurred at Double Bay and one at Snake Point but for the remainder of the study oyster borer density remained considerably lower at these two sites.

At the start of the study, oyster borer density at impact sites was below 3 individuals per m^2. Abundance increased at Golden Point, Kahikatea and Monkey Bay, peaking between February 2005 and March 2008 and again in March 2014 (Figure 19). Oyster borer density remained low at all other impact sites.

Oyster borer snails were always more abundant in the pooled reference treatment compared to the impact treatment (t = 5.75, P< 0.001). This difference was primarily due to the high numbers of snails at Umuwheke and periodically at Double Bay and Snake Point. 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 reference treatment in most years after February 2007. Pooled impact values increased till 2008 and then declined in 2009 only to increase again through to 2014. In 2017 their density again declined. Overall, mean values for both treatments increased over the duration of the study (Reference slope = 0.79, r^2 = 59.8%, P<0.001; Impact slope = 1.09, r^2 = 35.7%, P = 0.018).

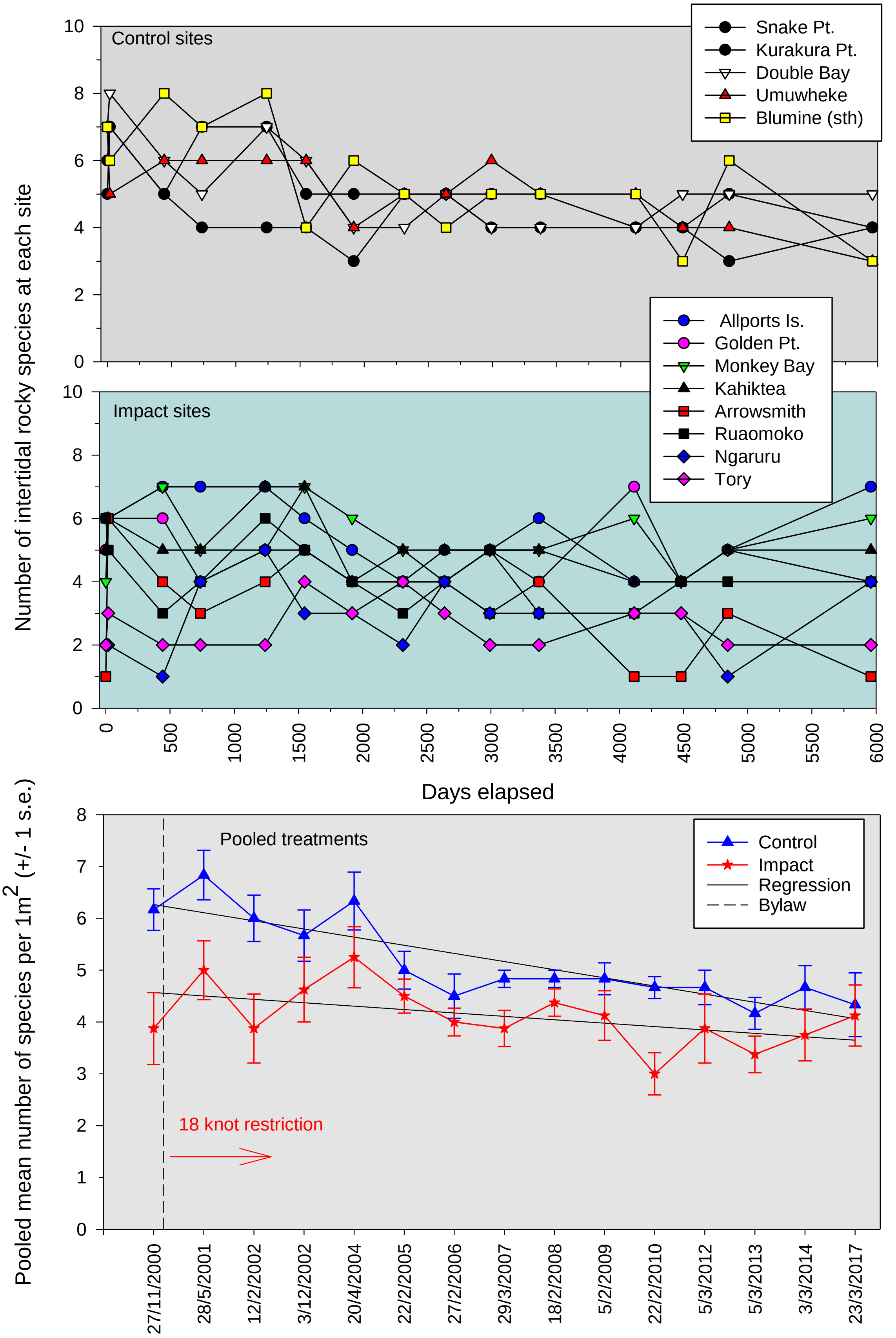


Figure 15. Number of mobile (detachable) mollusc species at intertidal bedrock reference and impact sites from November 2000 to March 2017 ($^{+}$/- 1 S.E.).

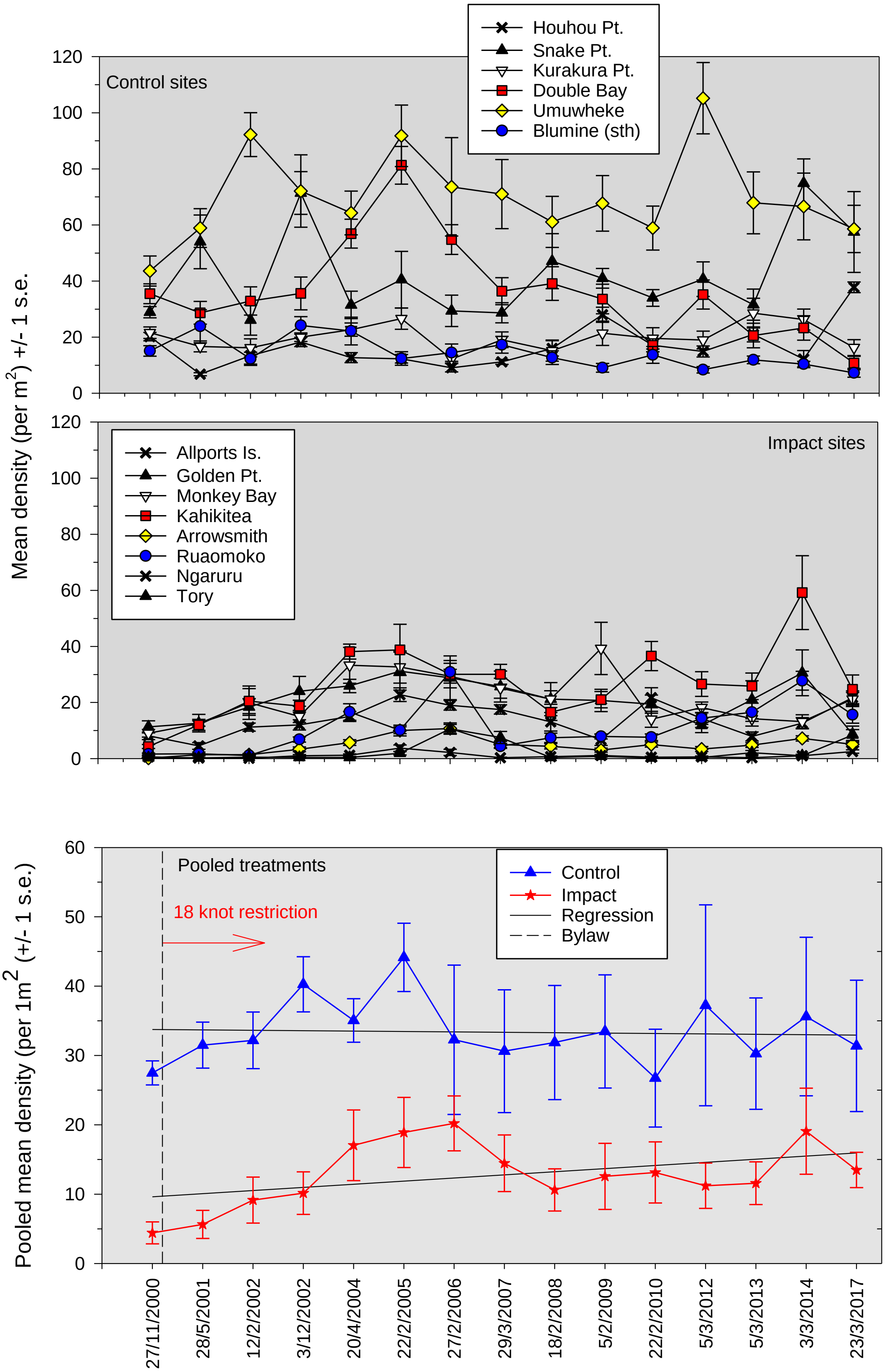


Figure 16. Density of mobile molluscs at intertidal bedrock reference and impact sites from November 2000 to March 2017 ($^+$/- 1 S.E.).

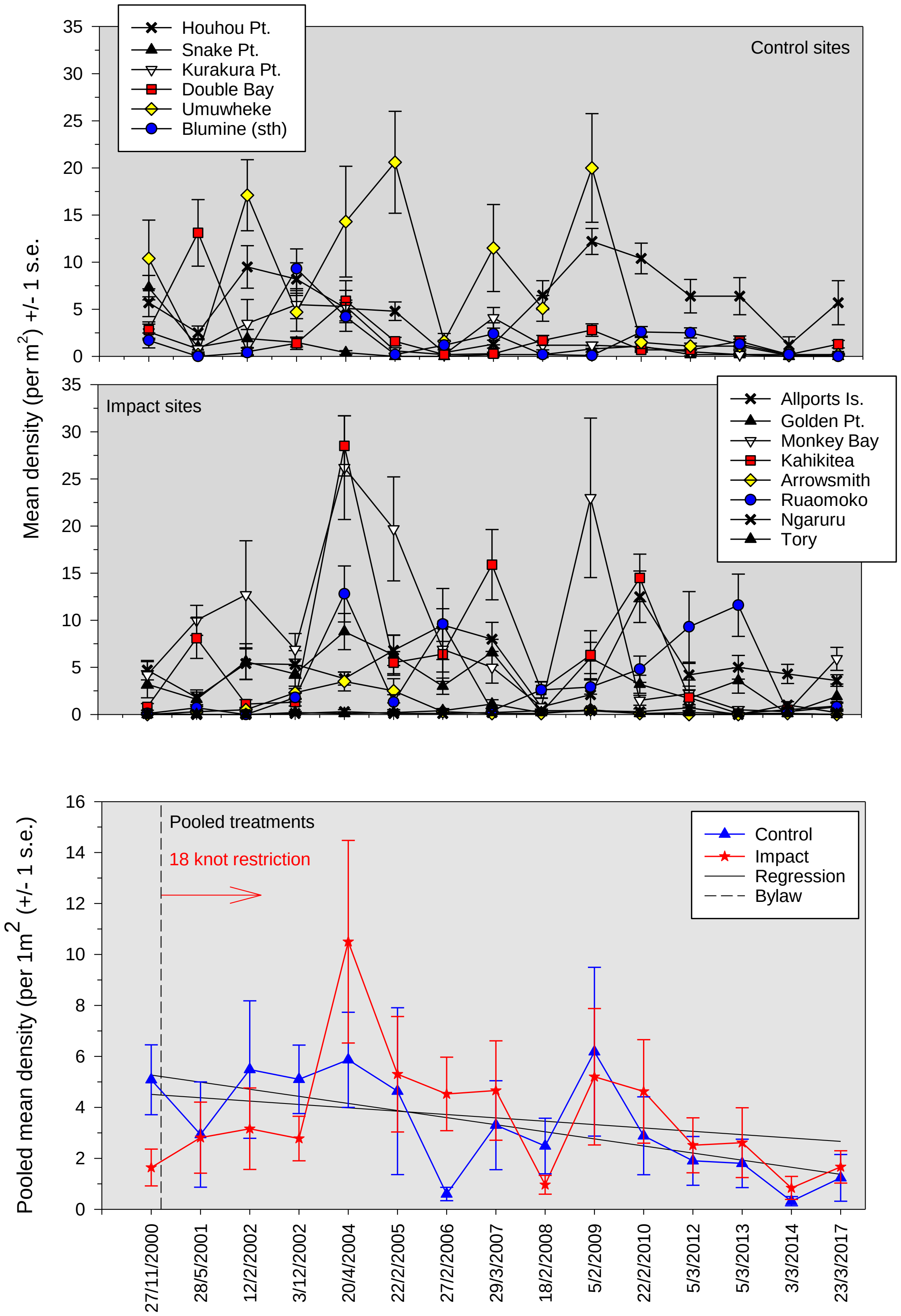


Figure 17. Mean density of cats-eye snail (*Turbo smaragdus*) from intertidal bedrock reference and impact sites and pooled treatments from November 2000 to March 2017 ($^{+}$/- 1 S.E.).

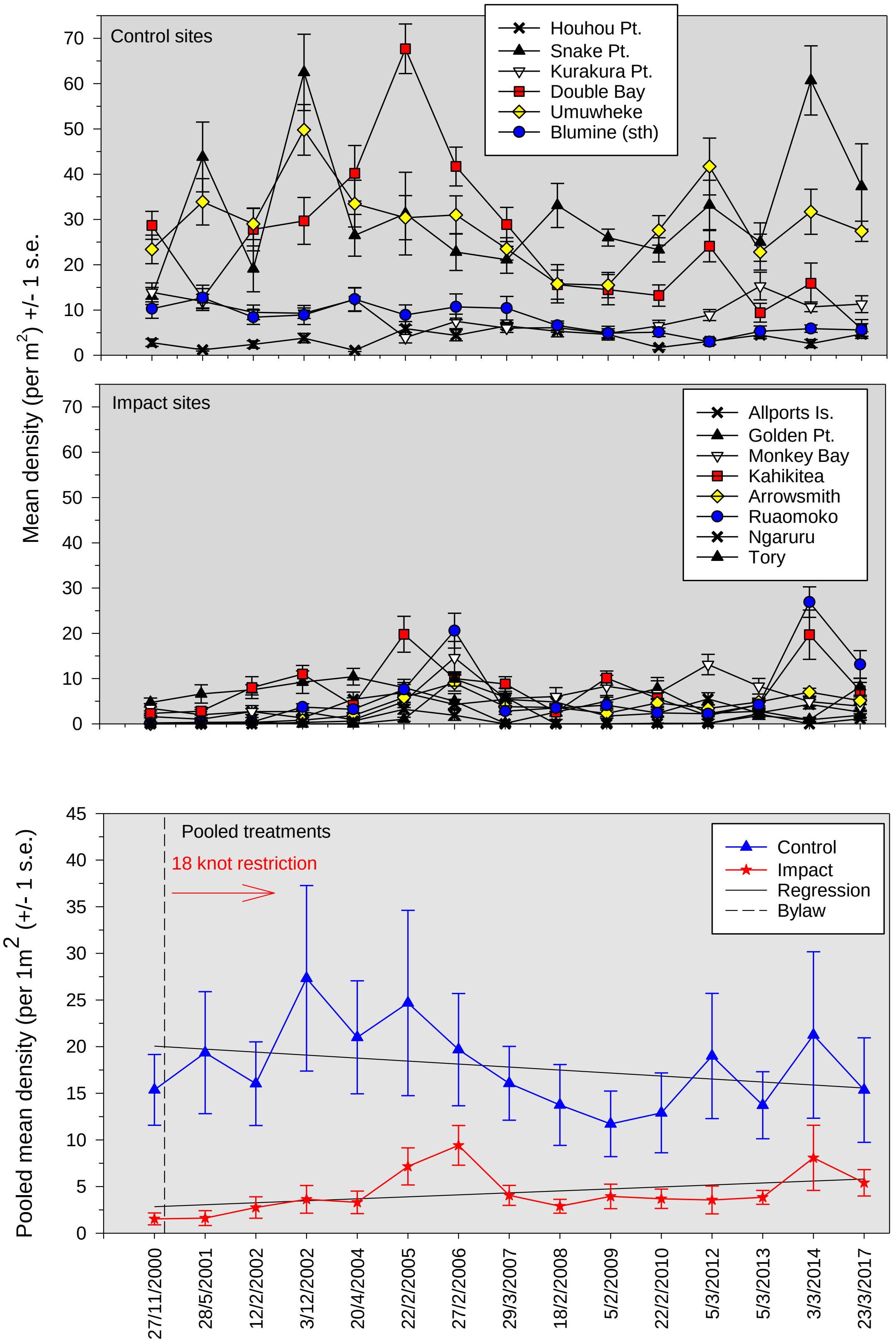


Figure 18. Mean density of topshell (*Melagraphia aethiops*) from intertidal bedrock reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

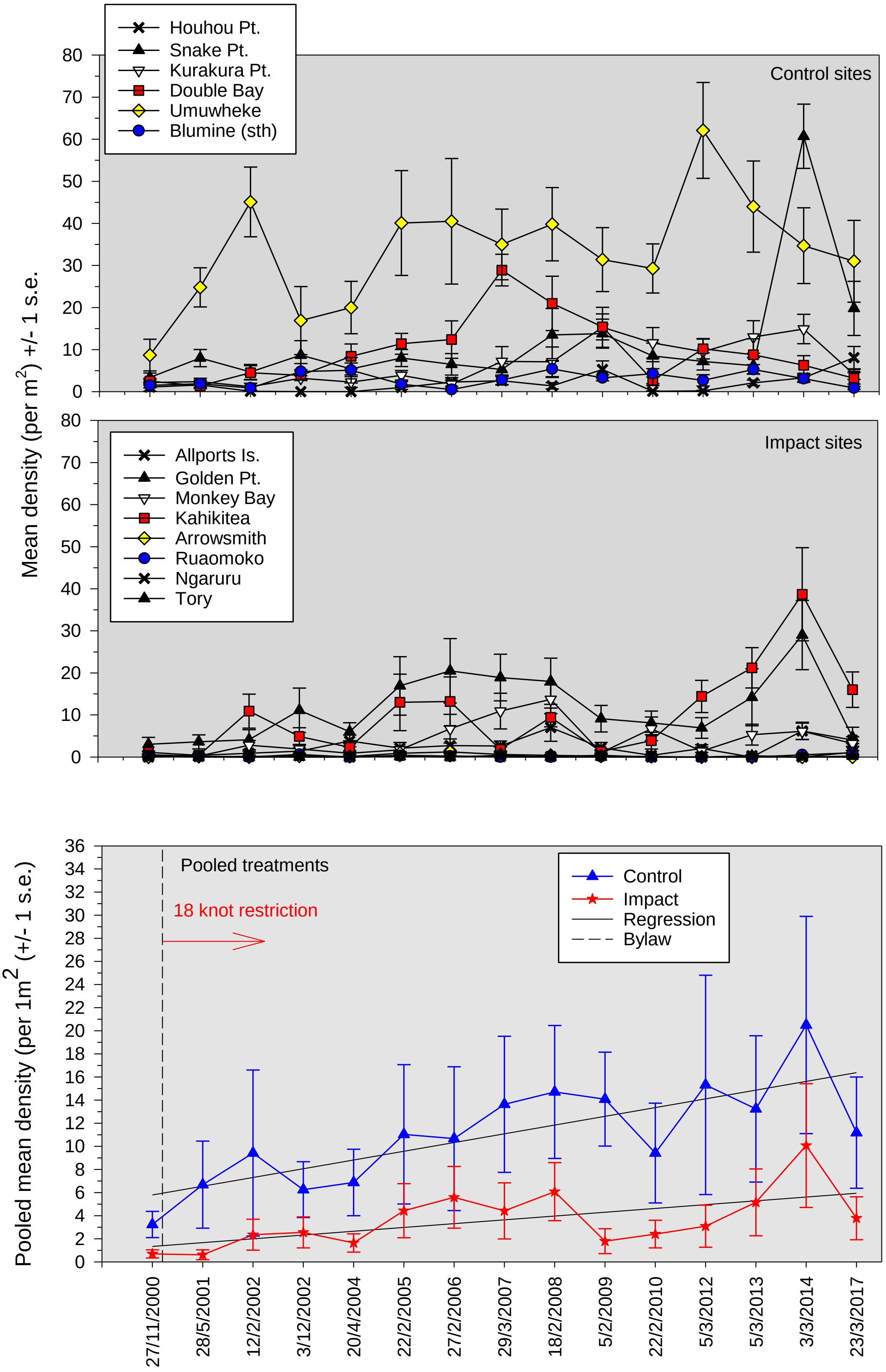


Figure 19. Mean density of oyster borer (*Lepsiella scobina*) from intertidal bedrock reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

4.4 Subtidal bedrock (0-0.5 m depth)

4.4.1 Macroinvertebrates (subtidal bedrock 0-0.5 m)

Species number

The number of shallow subtidal bedrock invertebrate species from reference sites ranged from 7 to 13 target species compared to 1 to 14 species at impact sites (Figure 20). No reference site exhibited an upward or downward trend over the duration of the study. Impact sites at Ngaruru and Arrowsmith (Tory Channel) had the lowest numbers of species and showed an increase after the Bylaw was implemented. Other impact sites consistently supported more species with some exhibiting an increase in the number of species over the duration of the study (Figure 20).

Pooled reference treatment density values were variable throughout the study and showed a small increase over the study (regression slope = 2.52, r^2 = 13.8%, P = 0.172). Mean number of species from the pooled reference treatment ranged from 8.2 to 10.6 per m^2, with lows in November 2000, February 2006 and March 2012 (Figure 20). In contrast, the pooled impact mean started low in comparison to the reference treatment with a mean of four species per m^2, but increased to a maximum of 9.5 species per m^2 by the end of the study (regression slope = 2.12, r^2 = 35%, P = 0.02). This maximum was close to the highest peak for the reference treatment (i.e. 10.6 species) (Figure 20). Pooled reference means were significantly higher than impact means (T = 133, P< 0.001).

Densities

The total density of target invertebrate species at shallow subtidal bedrock reference sites ranged from 6.2 to 46 individuals per m^2 compared to 0.8 to 85 per m^2 for impact sites (Figure 21).

The reference site at Snake Point had generally higher densities than other reference sites, followed by Double Bay and Umuwheke Bay. Houhou Point generally supported the lowest density of shallow subtidal bedrock species.

Impact sites located in Tory Channel (Arrowsmith and Ngaruru) mostly supported the lowest density of shallow subtidal species. Ngaruru showed little change after the Bylaw, while

Arrowsmith had a small increase (Figure 21). Kahikatea, Monkey Bay, and Allports all showed increases after the start of the study. A very large increase in the density of shallow invertebrates followed by a decline occurred at Kahikatea.

Pooled reference density values were variable throughout the study and showed a slight overall increase; however, the regression line was a poor fit (slope = 0.02, r^2 = 0.03%, P = 0.95). There were several highs and lows throughout the study, often coinciding across sites (Figure 21).

For the impact treatment, pooled mean density increased (regression slope = 0.29, r^2 = 31.9%, P=0.028) from an initial low in November 2000 to a high in February 2006, but subsequently declined through to 2010. Mean impact densities increased to remain largely above the reference treatment from February 2006 onwards (Figure 21). For most of the study error bars were overlapping due to considerable between-site variability. Overall mean values for the two treatments were not significantly different (T = 199, P = 0.171).

4.4.2 Kina (subtidal bedrock 0-0.5 m)

The abundance of kina was highly variable between sites, ranging from 0 to 20.5 individuals per m^2 at reference sites and 0 to 36.9 individuals per m^2 at impact sites. At reference sites, kina density remained relatively stable over the duration of the study with greatest fluctuations and generally highest densities recorded at Umuwheke (Figure 22).

Kina were consistently rare or uncommon from the reference site at Houhou Point and the impact sites at Ngaruru and Arrowsmith (Tory Channel) (Figure 22). These three sites also supported the highest abundances of macroalgae. At other impact sites, kina density generally increased from low values at the start and peaked several times throughout the study.

Overall, the difference between mean reference and impact treatments was significantly different (T = 306, P = 0.002). Mean kina densities at the pooled impact and reference treatments were comparable and increased between 2000 and 2002(Figure 22). Kina density at the impact treatment subsequently increased and remained well above densities recorded from the reference treatment for 2004 to 2014, before declining in 2017 (Figure 22).

Pooled mean density of kina for the reference treatment increased initially, consistent with the impact treatment, but subsequently remained relatively steady with some small peaks and throughs (reference regression slope = 1.06, r^2 = 15.1%, P = 0.15; impact regression slope = 0.59, r^2 = 29.5%, P = 0.036) (Note: reference regression was a poor fit).

At the end of the study, mean kina densities from the pooled impact treatment declined from the highs of 2004 to 2014 to match those recorded around 2002 (Figure 22). This decline was recorded at all individual impact sites excluding Ngaruru. A decline was, however, also recorded in 2017 at three reference sites over the same period.

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

At reference sites, cats-eye abundance was highly variable between sites ranging from 2.2 to 23.5 snails per m^2 compared to 0 to 45.4 individuals per m^2 at impact sites. Cats-eye density at reference sites remained relatively stable over the duration of the study with only modest increases and decreases (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), but their abundance at these sites gradually increased over the study (Figure 23). At all other impact sites, snail density increased from early lows to dramatically higher numbers between December 2006 and 2009; this large increase was most pronounced at Kahikatea and Monkey Bay. A large decrease in the number of snails occurred at four of the six impact sites in February 2010 and this trend continued for the following three years with a small increase in 2017. Densities remained comparable to reference sites over this latter period.

The density of cats-eye from the pooled reference treatment at shallow bedrock sites remained relatively stable over the duration of the study with small peaks and lows. The regression line was slightly negative but a poor fit (regression slope = -0.373, r^2 = 2.4%, P = 0.58). Snail density at the pooled impact treatment increased steadily to a high in February 2009, followed by a decline to levels matching the pooled reference sites for the remainder of the study (Figure 23). Overall, subtidal bedrock cats-eye densities increased for the impact treatment over the study duration, but the regression was a poor fit (regression slope = 0.382, r^2 = 15.9%, P = 0.141). The impact and reference treatments were not significantly different (T = 211, P = 0.384).

4.4.4 Top shell (subtidal bedrock 0-0.5 m)

The abundance of top shell (*Trochus* sp.) ranged from 0 to 7.5 individuals per m^2 at reference sites compared to 0 to 7.3 individuals per m^2 at impact sites. Apart from two occasions at two different sites, top shell densities remained below 5 individuals per m^2 (Figure 24). The density of top shells at all but one impact site changed little over the duration of the study. Top shells were absent or rare from Ngaruru and Arrowsmith. A relatively large increase in top shell abundance occurred at Allports Island, peaking in March 2013 before declining back to earlier levels.

For the pooled reference treatment, topshell density was highest over the first year of the study due to high numbers at Kurakura and Houhou Points. From February 2002, impact and reference pooled treatments remained very similar with error bars consistently overlapping (T = 194, P = 0.114).

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

Black-foot paua were recorded from four of the five subtidal bedrock reference sites and five of the six impact sites. When present, their density was low, ranging from 0 to 0.3 individuals per m^2 at reference sites and 0 to 0.5 individuals per m^2 at impact sites (Figure 25).

Pooled treatment data showed more black foot paua were recorded from the impact treatment compared to the reference group (T = 159, P = 0.002). The mean density for the pooled impact treatment was variable and increased over the duration of the study, but the change was small and densities remained low (Figure 25).

4.4.6 11 arm seastar, kina and sea cucumber (subtidal bedrock 0-0.5 m)

Site data for 11 arm seastar, kina and sea cucumber collected from large quadrats (10 and 20 x 1 m^2) were pooled for each treatment (Figure 26).

Apart from in 2010, the density of 11 arm seastar (*Coscinasterias muricata*) was consistently higher from the pooled impact treatment compared to the reference treatment. Over the duration of the study, seastar density increased for both reference and impact treatments, the latter at a slightly shallower rate.

Kina (*E. chloroticus*) density from the pooled impact and reference treatments both increased over the duration of the study, the reference sites at a slightly shallower rate (Figure 26).

On most sample events, pooled sea cucumber densities were low at both the impact and reference treatments (Figure 26). No increasing or decreasing trends were apparent over the duration of the study. In some years, reference sites supported greater densities of sea cucumbers than at impact sites.

4.5 Subtidal bedrock (1.5-2 m depth)

4.5.1 Macroinvertebrates (subtidal bedrock 1.5-2 m)

Between 6 and 14 invertebrate species were recorded at deep bedrock reference sites compared to 2 to 11 species at impact sites. No dramatic increase or decrease was recorded from impact or reference sites over the duration of the study (Figure 27).

The pooled mean number of species remained higher at reference sites compared to impact sites for the duration of the study ($t = 6.818$, $P < 0.001$) (Figure 27), consistent with data from shallow subtidal bedrock (Figure 20). Highs and lows usually occurred in the same years for both treatments.

Houhou Point (reference site) and Ngaruru and Arrowsmith (impact sites) consistently supported the lowest densities of invertebrates (0.1 to 10.4 individuals per m^2). The remaining impact and reference sites had comparable densities of invertebrates. Highest numbers of invertebrates were often recorded from the Kahikitea impact site.

The pooled data for the impact and reference treatments were generally comparable, following slightly different, but overlapping patterns (Figure 28).

4.5.2 Kina (subtidal bedrock 1.5-2 m)

The abundance of kina from deep subtidal bedrock ranged from 0 to 12.3 individuals per m^2 at reference sites and 0 to 13.5 per m^2 at impact sites. At reference sites, abundance was variable between years with density peaking at many sites on several occasions (Figure 29). Kina density at reference sites was consistently lowest at Houhou Point and highest from Umuwheke, Kurakura and Double Bay. Urchins were absent or rare at Ngaruru and

Arrowsmith and their density fluctuated at other impact sites (Figure 29). As for shallow samples, kina were least common from sites with a high cover of macroalgae.

For both pooled impact and reference treatments, the density kina from deep subtidal bedrock followed a comparable upward trend throughout the study (regression control slope = 2.81, r^2 = 63.9%, P = 0.05; impact slope = 2.56, r^2 = 50.8%, P = 0.325) (Figure 29). There was no significant difference between the two treatments (t = -1.827, P = 0.08).

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 reference sites compared to 0 to 32.7 individuals per m^2 at impact sites. At reference sites, snail density remained relatively stable between sites over the duration of the study with no large increases or decreases (Figure 30). The density of snails was consistently low at Houhou Point and highest from Snake Point, Umuwheke and Double Bay.

Cats-eyes were absent or rare at the Ngaruru and Arrowsmith impact sites (Figure 30). The Allports impact site supported comparable snail densities to most reference sites. At the remaining impact sites, cats-eye density from deep bedrock sites regularly exceeded densities recorded from reference sites peaking in February 2008. Overall, cats-eye densities at impact and reference sites ended close to where they started.

For the pooled reference treatment, mean cats-eye density remained relatively stable throughout the study, with only minor fluctuations (Figure 30). Cats-eye density from the pooled impact treatment was always higher compared to the reference treatment (T = 343, P<0.001), however, error bars did overlap for all but three sample occasions (Figure 30). The impact treatment increased relative to the reference treatment between 2002 and 2008, peaking in March 2008, before returning to levels recorded in the early years of the study.

4.5.3 Topshell (subtidal bedrock 1.5-2 m)

The abundance of the topshell (*Trochus* sp.) ranged from 0 to 11.2 individuals per m^2 at reference sites compared to 0 to 6.6 individuals per m^2 at impact sites. Topshell density varied at all reference sites over the duration of the study, with lowest numbers generally recorded at Snake Point (Figure 31).

The density of topshells at all but one impact site changed little over the duration of the study. Topshells were absent or rare from sites where macroalgae was abundant (i.e. Ngaruru and Arrowsmith). A relatively large increase in topshell abundance occurred at Allports Island, peaking in March 2008 and again in 2014, before returning in 2017 to previously recorded low levels (Figure 31).

For the pooled reference treatment, topshell density fluctuated throughout the study with peaks in May 2001, April 2004, February 2008 and March 2013 (Figure 31). Topshell density at pooled reference sites declined over the course of the study (Reference slope = -2.21, r^2 = 10.4%, P = 0.24), though this trend was not significant given the poor fit to the regression line.

Mean topshell density for the pooled impact treatment followed similar fluctuations as the reference treatment apart from delayed peaks in February 2005 and March 2014 (Figure 31). In contrast to the reference treatment, abundance tended to increase slightly over time (Impact slope = 2.9, r^2 = 7.5%, P = 0.325) though again there was a poor fit to the regression line.

Except on one occasion, densities from the pooled impact treatment were always lower than those recorded from the reference treatment. This difference was significant despite error bars overlapping on several occasions, especially in the latter half of the study (t = -3.894, P<0.001). Despite these differences, both treatments followed very similar fluctuations over time (Figure 31).

4.5.4 Black foot paua (subtidal bedrock 1.5-2 m)

Black foot paua were rarely recorded from deep impact and reference sites; therefore, no graphs were generated for this species.

4.5.5 11 arm sea star, kina and sea cucumber (subtidal bedrock 1.5-2 m)

Apart from two sample occasions, 11 arm sea stars were more abundant from the deep bedrock impact treatment compared to the reference treatment (Figure 32). Seastar density fluctuated in both treatments but showed large change over the course of the study other than a small increase as indicated by the positive repression slope for both treatments (regression slope reference = 19.1, r^2 = 14%, P=0.02; impact slope = 12.24, r^2 = 2.6%, P=0.225) (Note: impact regression line was a poor fit).

Kina density at the pooled impact and reference treatment were very similar over the duration of the study (Figure 32) and followed a similar upward trend (regression slope reference = 1.61, r^2 = 22.8%, P=0.072; impact slope = 1.88, r^2 = 31.9%, P=0.028).

Sea cucumber densities were higher at the reference treatment at times; however, the differences were often small (Figure 32). Densities fluctuated in both treatments, though not in unison. Impact densities increased to a small degree for the impact treatment (regression impact slope = 12.84, r^2 = 9.0%, P = 0.28).), while the reference density finished lower than it started but with a slight downward slope (regression reference slope = -3.06, r^2 = .5%, P = 0.81). (Note: impact regression line was a poor fit for both treatments).

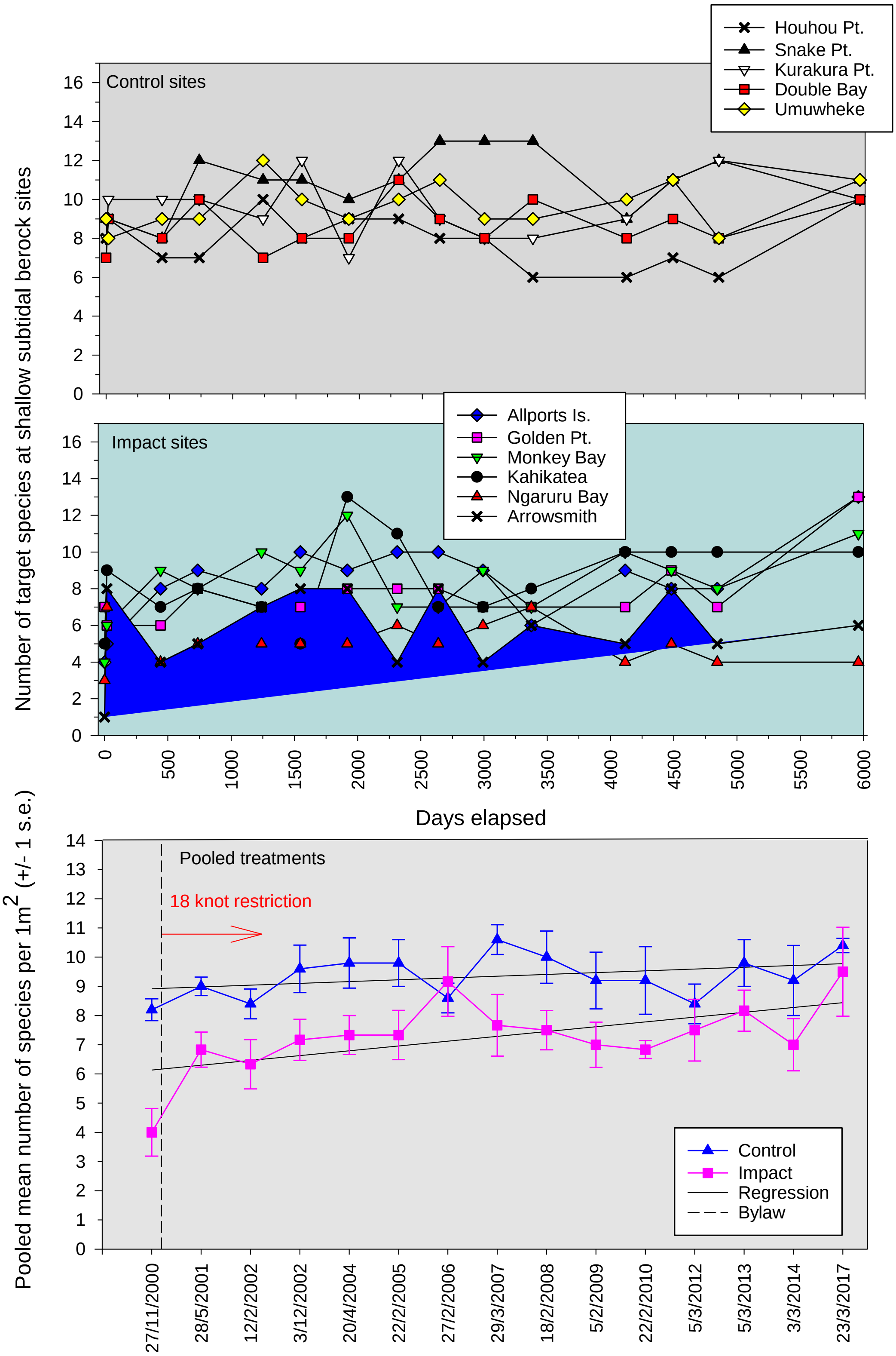


Figure 20. Number of target species recorded from shallow subtidal bedrock (0-0.5 m depth) reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

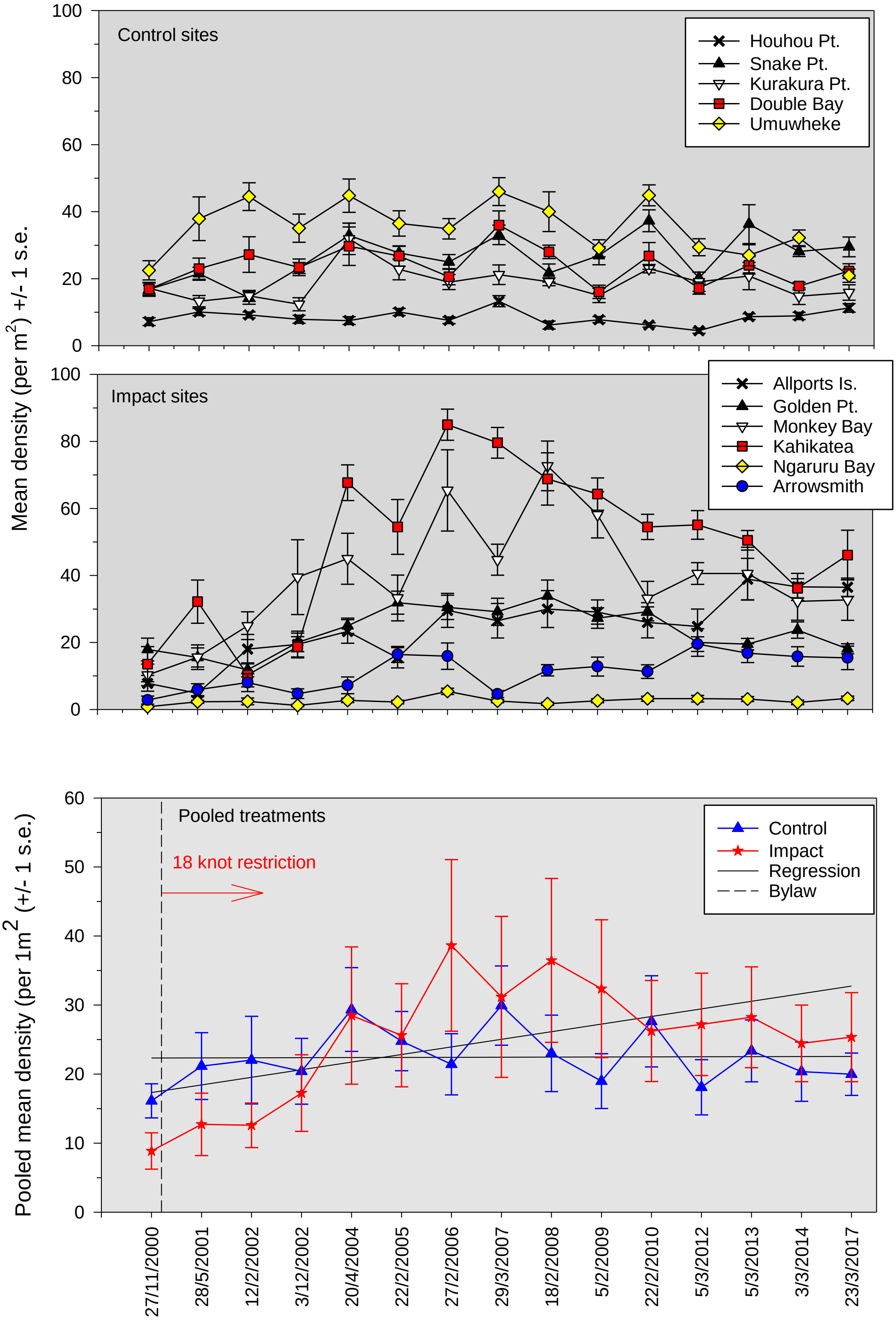


Figure 21. Mean density of all species recorded from shallow subtidal bedrock (0-0.5 m depth) reference and impact sites and pooled treatments from November 2000 to March 2017 ($^{+}$/- 1 S.E.).

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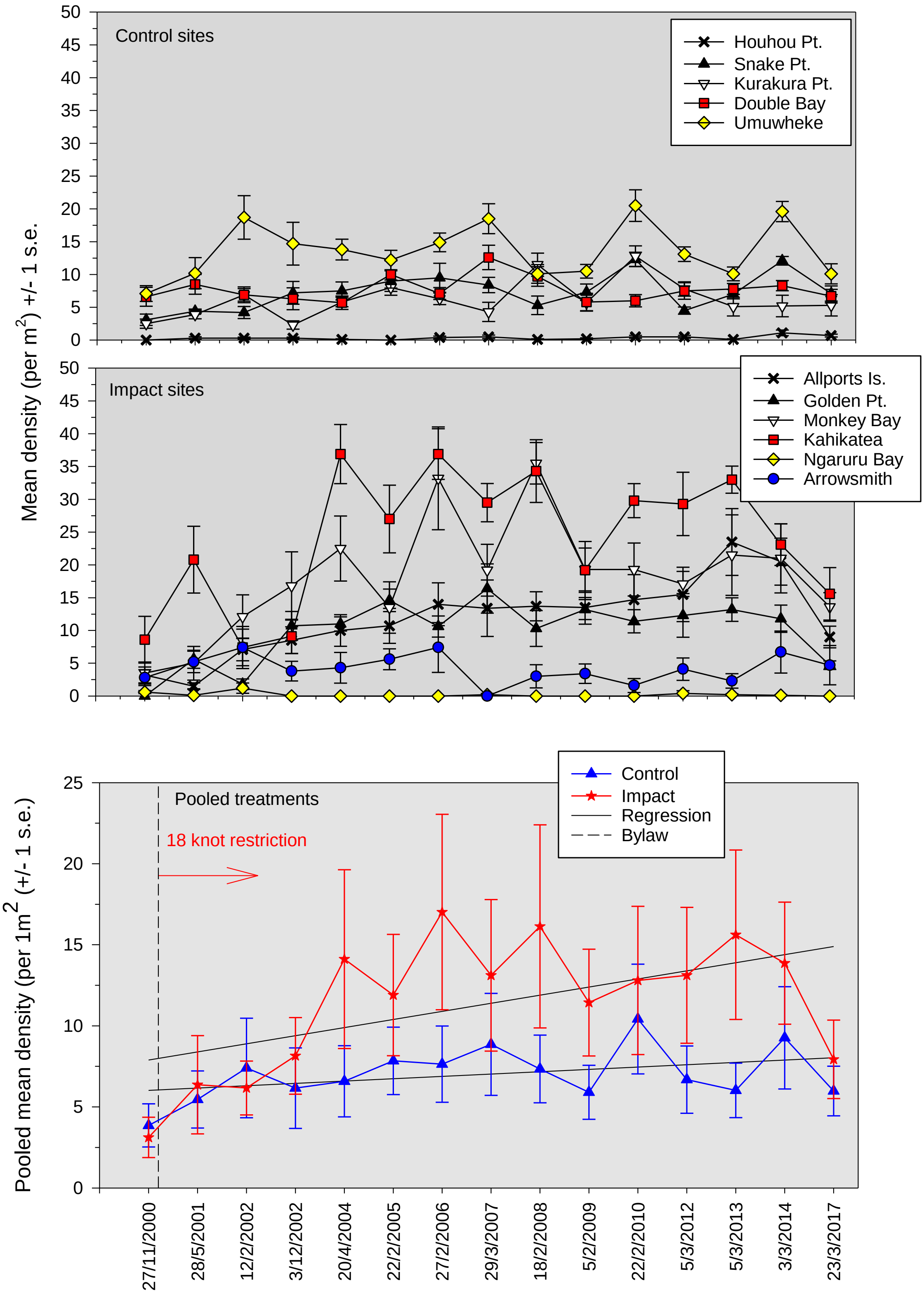

Figure 22. Mean density of kina recorded from shallow subtidal bedrock (0-0.5 m depth) reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

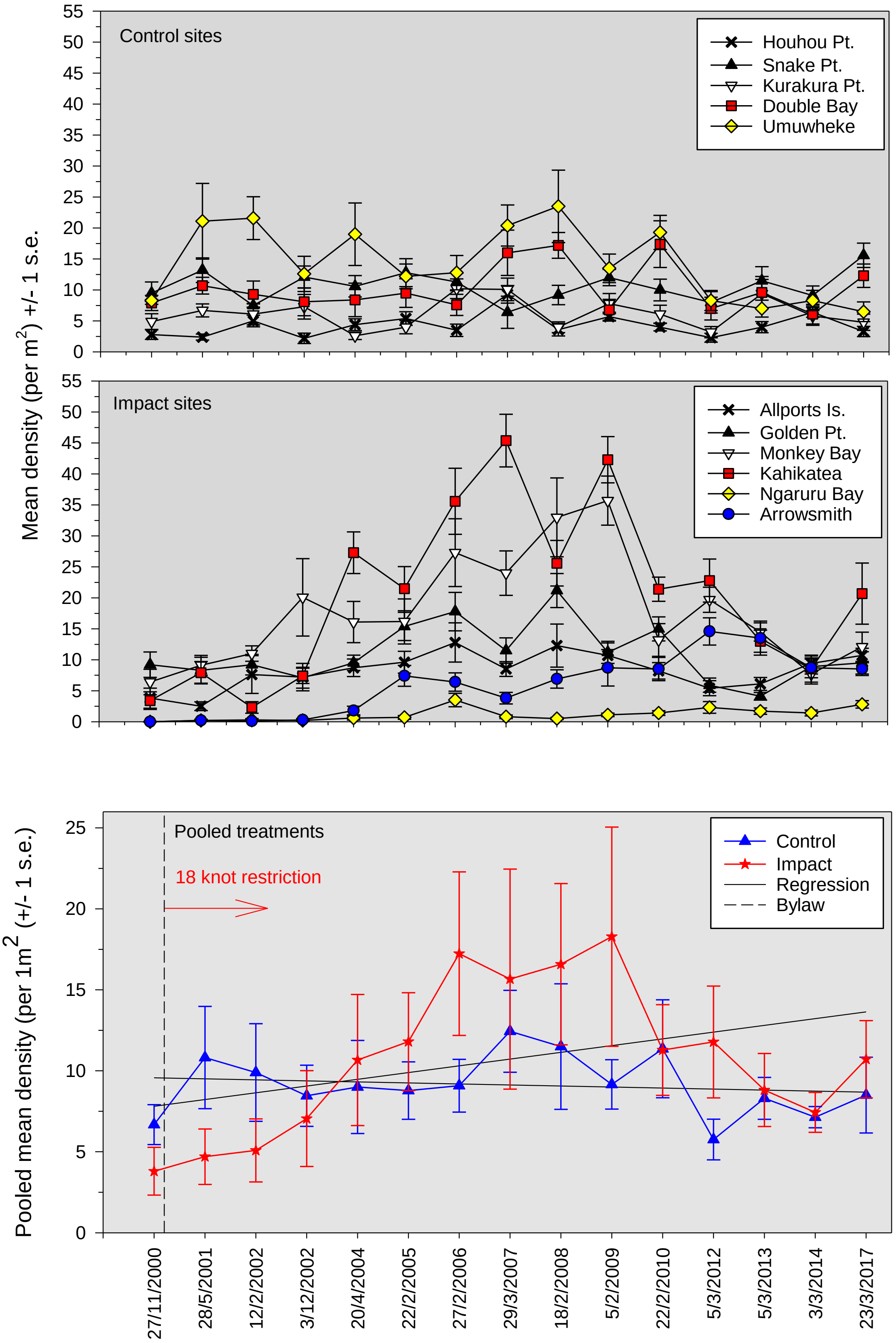

Figure 23. Mean density of cats-eye snails recorded from shallow subtidal bedrock (0-0.5 m depth) reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

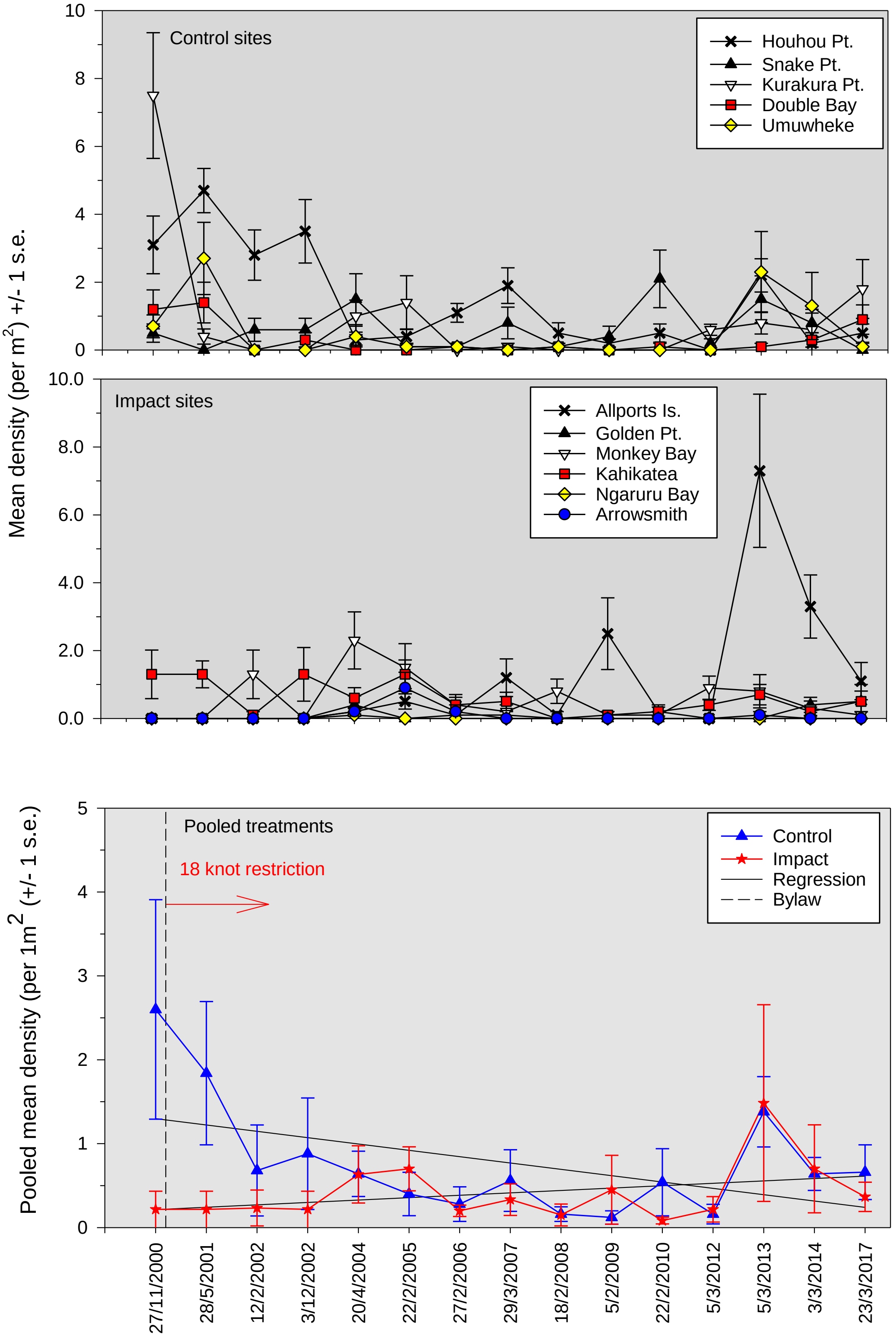

Figure 24. Mean density of topshell (*Trochus* sp.) from shallow subtidal bedrock (0-0.5 depth) from reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

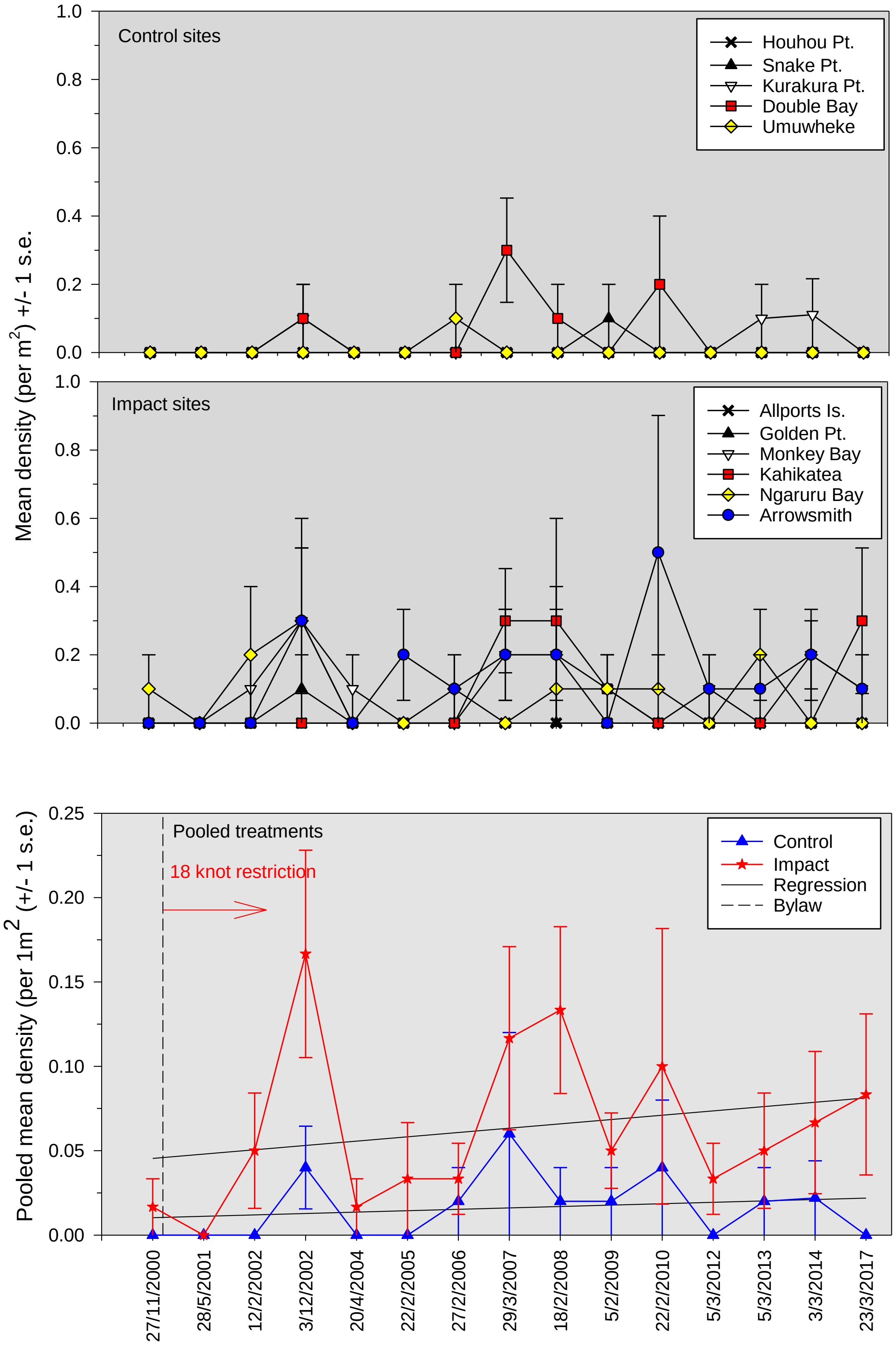

Figure 25. Mean density of black-foot paua (*Haliotis iris*) at shallow subtidal bedrock (0-0.5 m depth) reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

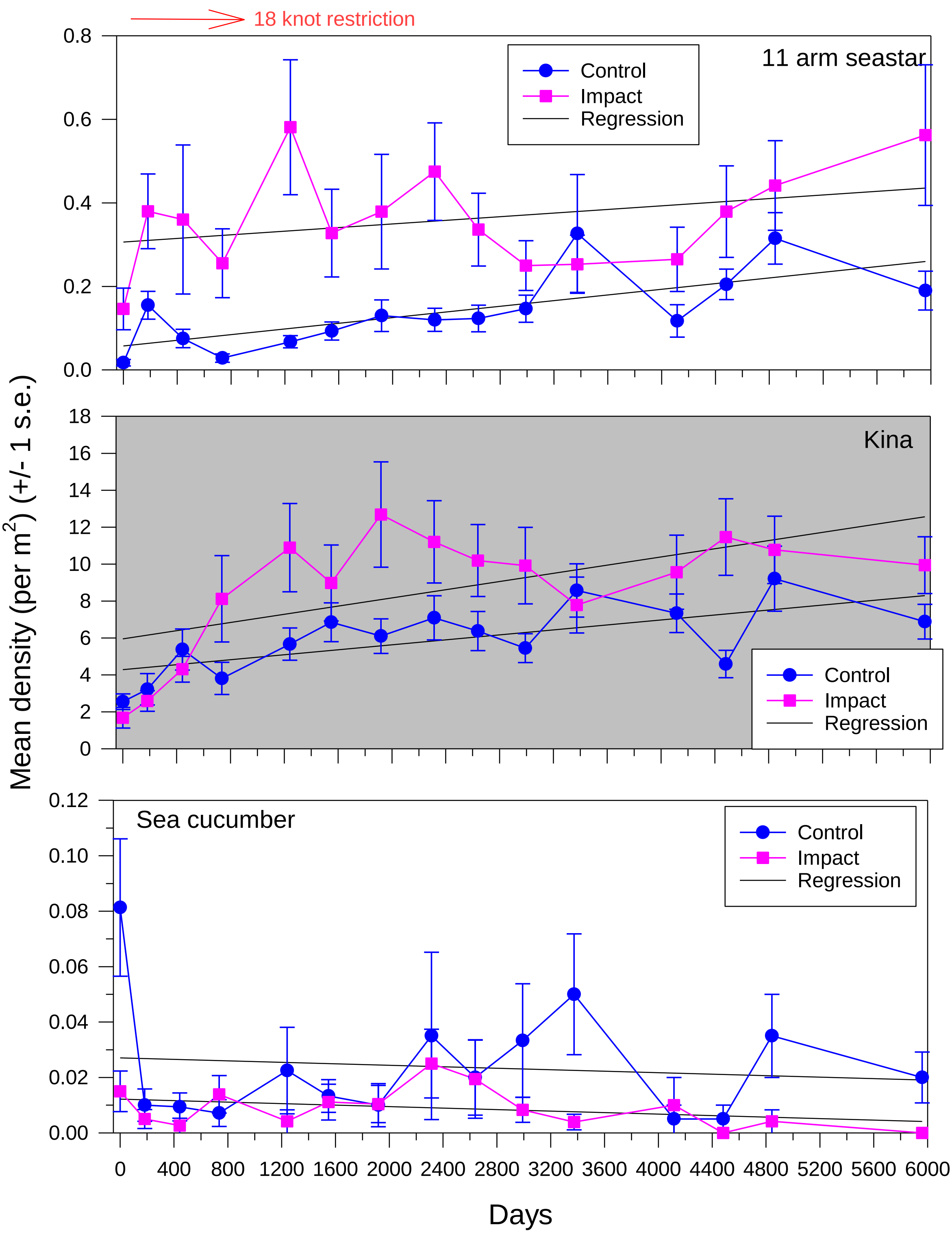

Figure 26. Mean density of three selected species recorded from shallow subtidal bedrock (0-0.5 m depth) reference and impact pooled treatments from November 2000 to March 2017 ($^{+}$/- 1 S.E.).

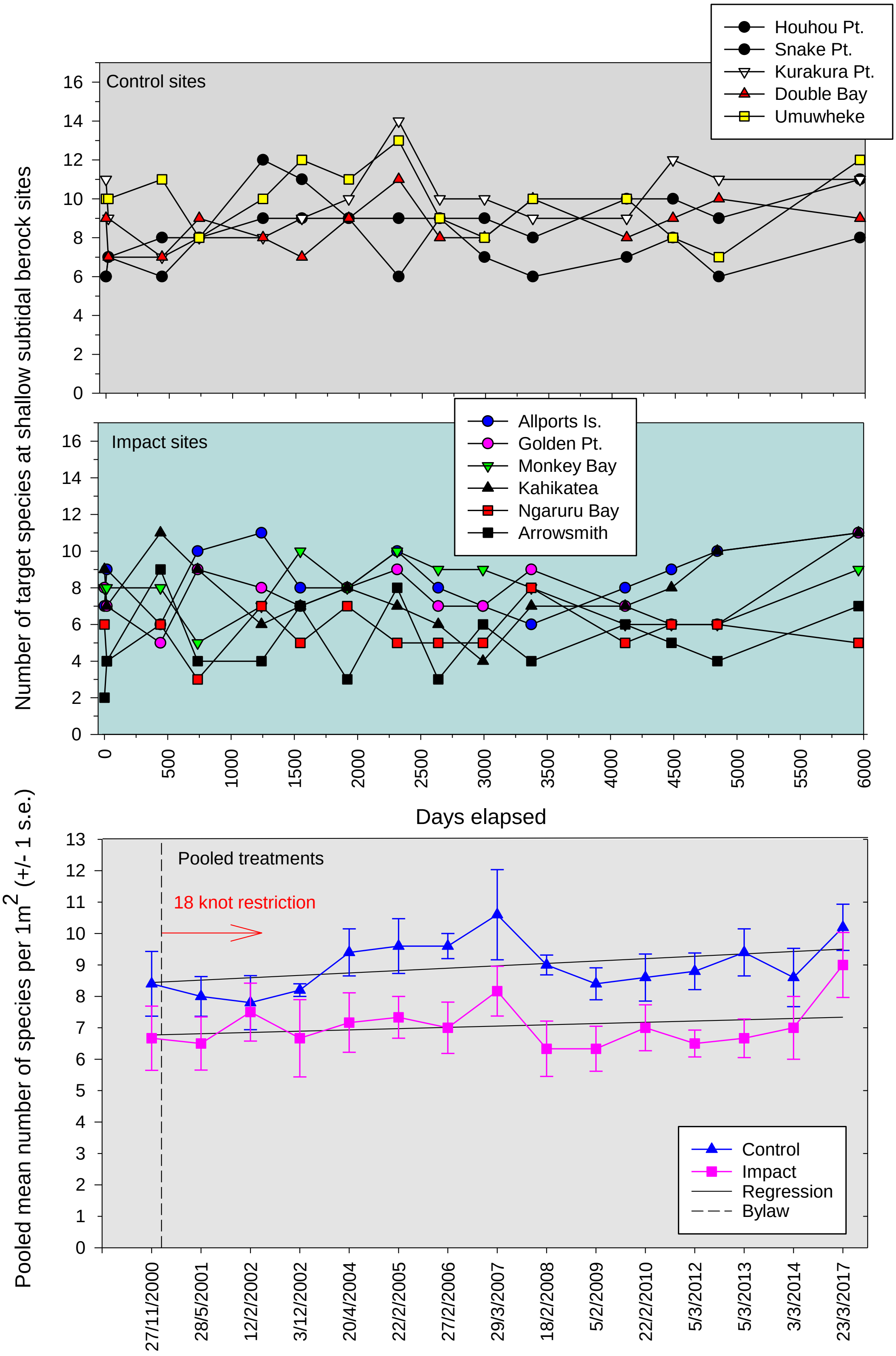

Figure 27. Number of target species recorded from deep subtidal bedrock (1.5-2.0 m depth) from reference and impact sites and mean pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

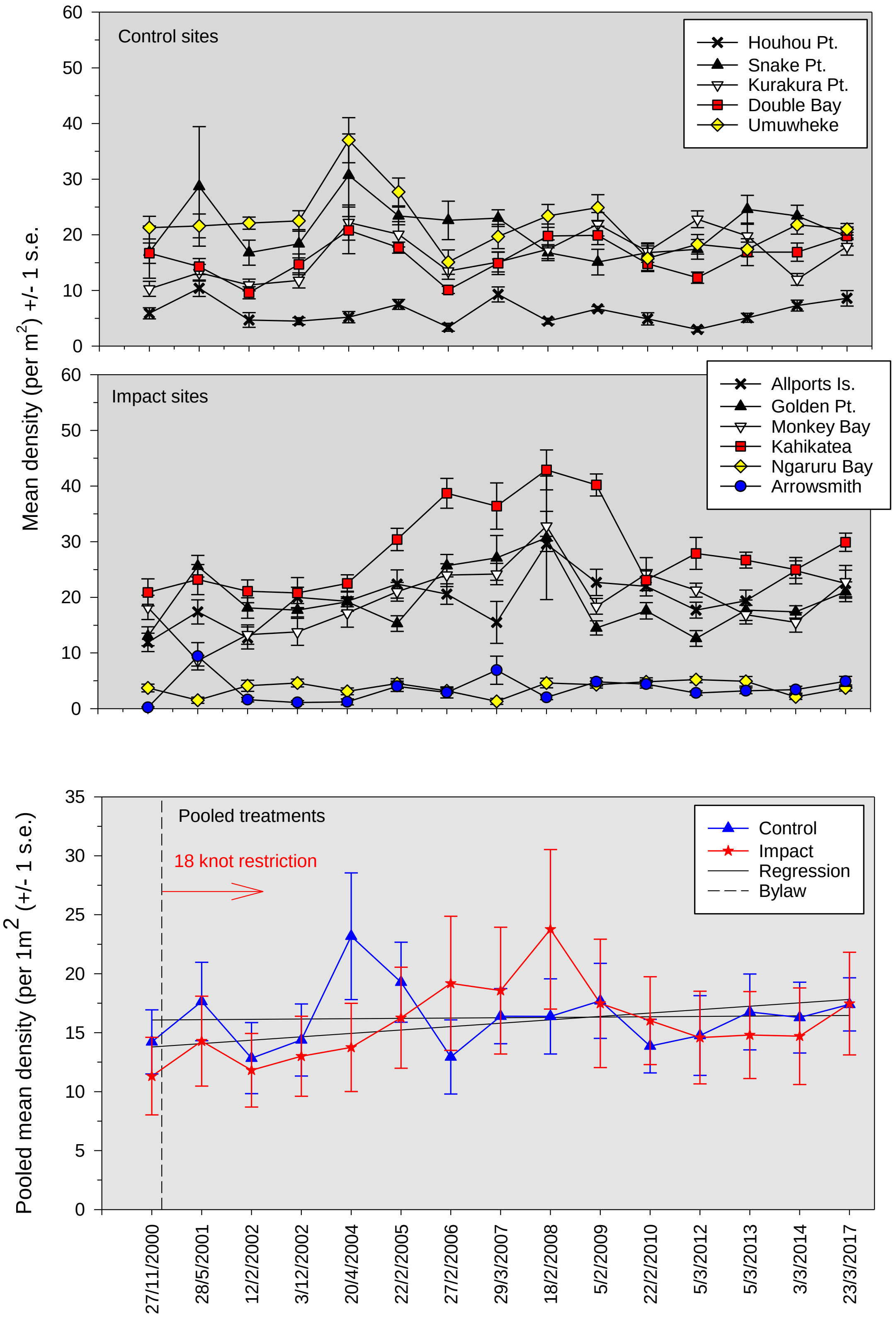

Figure 28. Mean density of target species recorded from deep subtidal bedrock (1.5-2.0 m depth) from reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.).

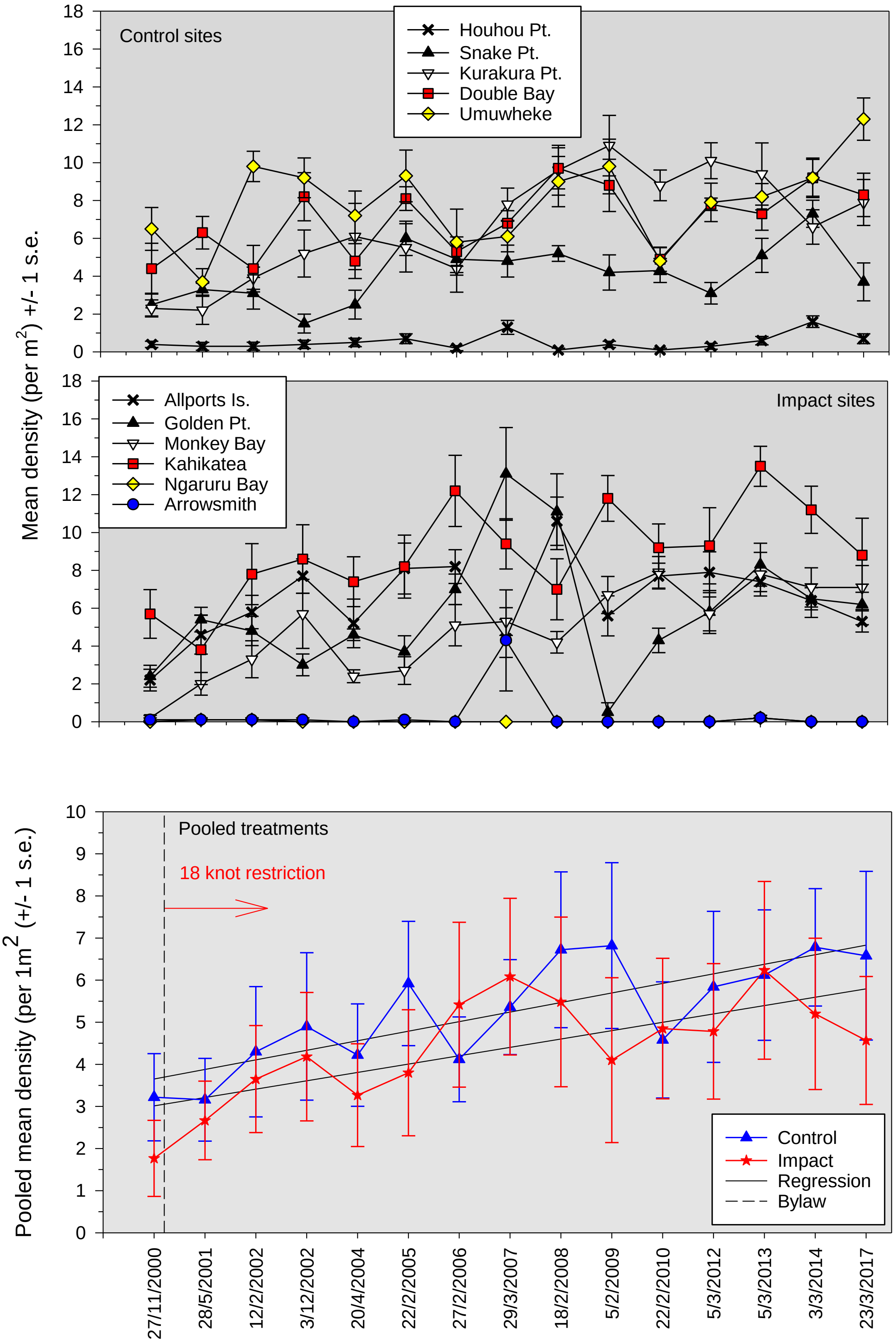

Figure 29. Mean density of kina recorded from deep subtidal bedrock (1.5-2.0 m depth) from reference and impact sites and pooled treatments from Nov 2000 to March 2017 ($^{+}$/- 1 S.E.)..

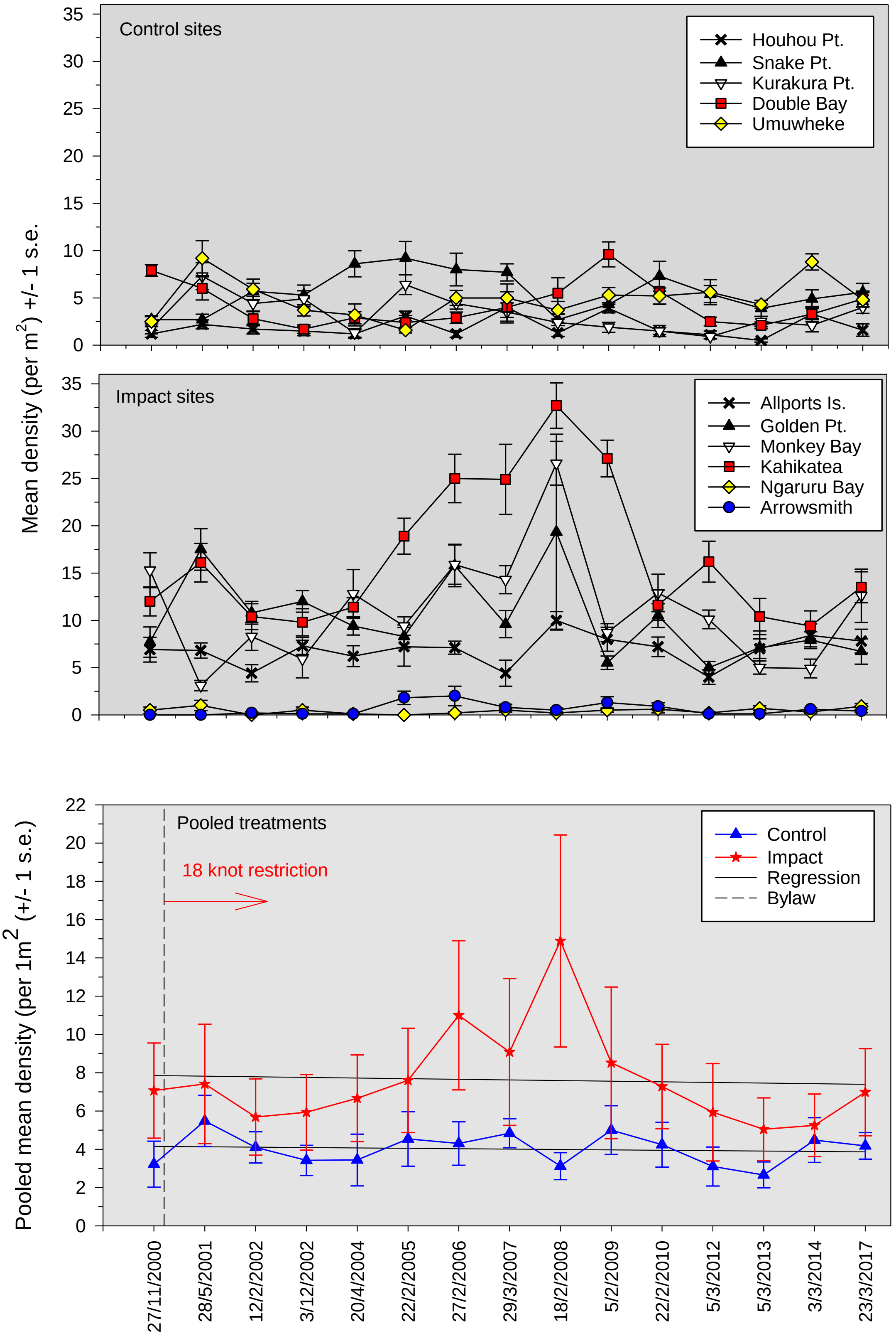

Figure 30. Mean density of cats-eye recorded from deep subtidal bedrock (1.5-2.0 m depth) from reference and impact sites and pooled treatments from November 2000 to March 2017 ($^+$/- 1 S.E.)..

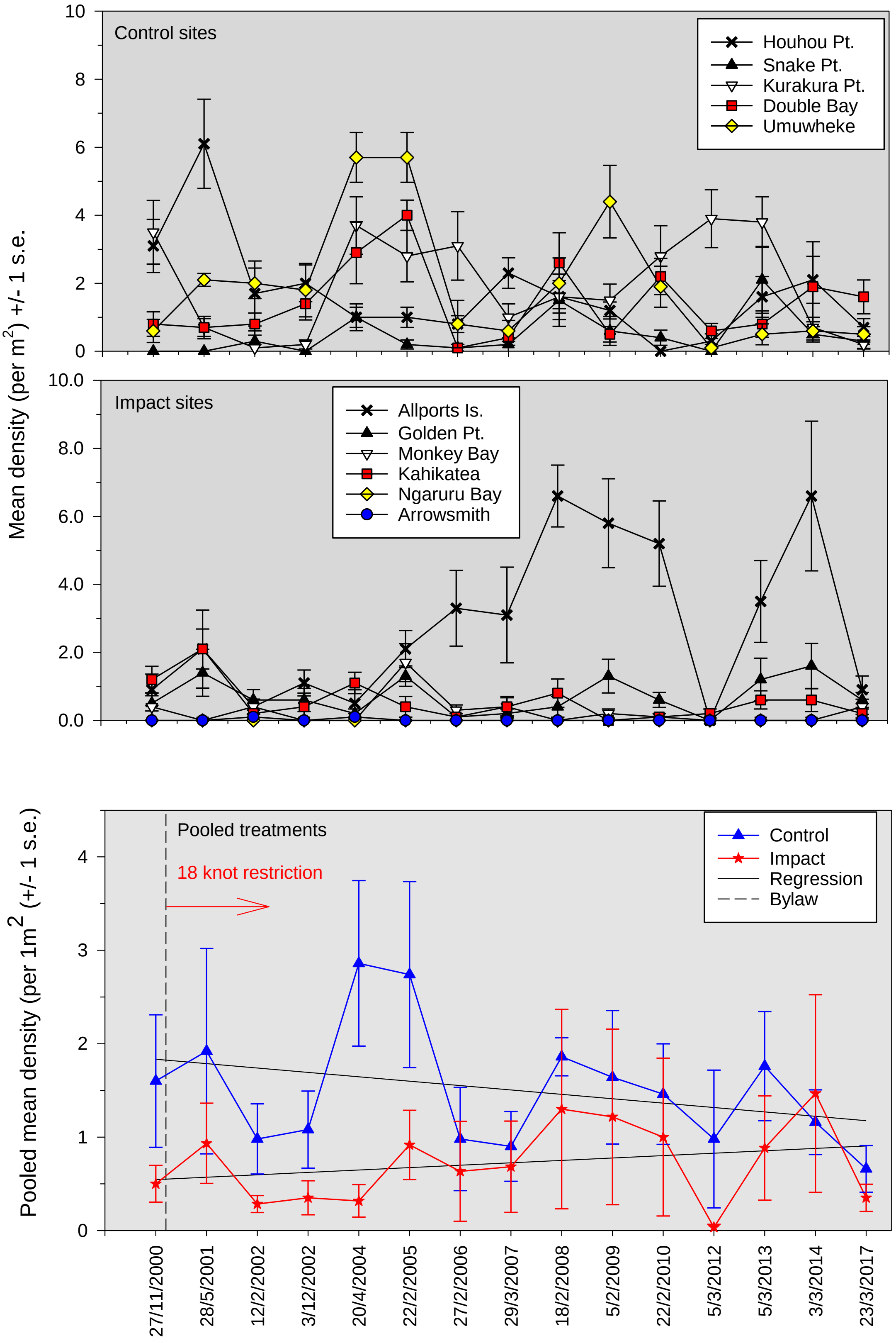

Figure 31. Mean density of top shell (*Trochus* sp.) from deep subtidal bedrock (1.5-2.0 m depth) from reference and impact sites and pooled treatments from November 2000 to March 2017 ($^{+}$/- 1 S.E.).

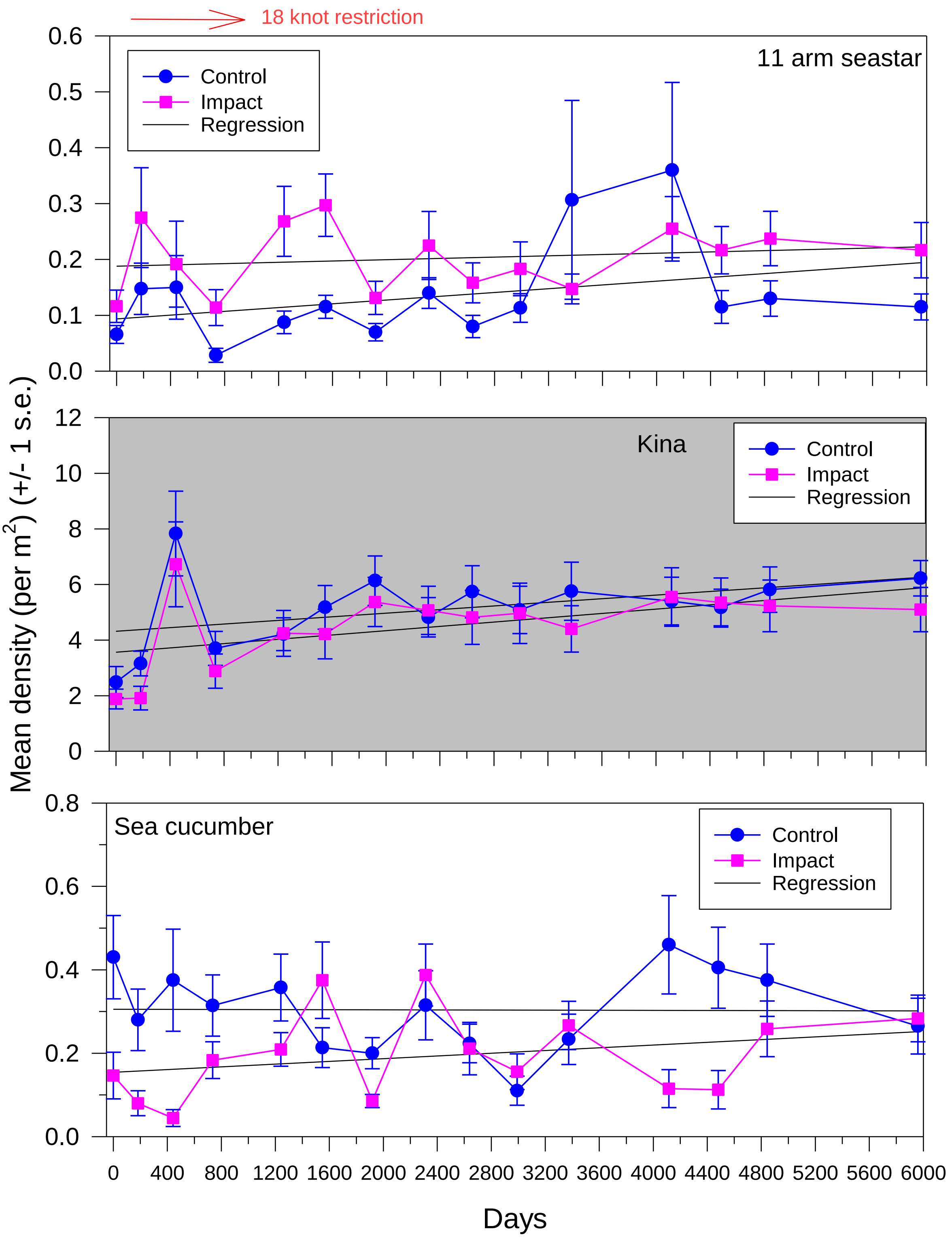

Figure 32. Mean density of selected species recorded from deep subtidal bedrock (1.5-2.0 m depth) reference and impact pooled treatments from November 2000 to March 2017 ($^{+}$/- 1 S.E.).

5.0 Discussion

New high-speed ferries were introduced between Picton and Wellington in the summer of 1995. Residents reported considerable biological change for the cobble shores of Tory Channel and central Queen Charlotte Sound. Biological surveys were initiated by various authors at many sites along the ferry route (Davidson 1995, 1996, 1997, 1998, 2002; Davidson and Richards 2005; Davidson *et al*., 2010; Gillespie 1996; Grange *et al*. 1995).

In December 2000, a navigational Bylaw was introduced restricting ferries to 18 knots unless they could adhere to a maximum wake criterion. Since that time, biological data have been collected to: (a) investigate the possible recovery of biological communities since the introduction of the bylaw; and (b) monitor the impact of conventional ferries.

The present study updates biological investigations initiated in 1995 by Davidson (1995) and continued by Davidson (2002) and Davidson *et al*. (2010), a period of 22 years.

5.1 Selection of reference and impact sites

Reference and impact sites were selected to match natural environmental variables as much as possible to ensure comparability between sites. For intertidal bedrock and cobble-small boulder shores, this was achieved through selection of shores with comparable aspects, slopes and substrata. However, finding suitable reference sites for subtidal shores in Tory Channel was difficult as the biological environment and associated communities are unique to this part of the Marlborough Sounds (Davidson *et al*., 1995; Davidson *et al.,* 2011). The reference site at Houhou Point, inner Queen Charlotte Sound, was chosen because of its cover of macroalgae, and while there was a lower biomass and a different range of macroalgae species, the presence of a macroalgal canopy provided some similarities. The other reference sites were less comparable to Tory Channel sites due to the absence of a widespread macroalgal canopy.

Davidson (2002) sampled subtidal bedrock shores at two depth strata. The author suggested that ferry wash would more likely have an impact on the shallow strata, while the deeper strata could be free from ferry wake impacts or suffer minimal effects due to its greater depth. The author also suggested comparison of biological data from deeper bedrock shores could help assess comparability of reference and impact sites. Any major differences detected between deep reference and deep impact shores suggests sites were naturally different and therefore unsuitable for use.

Davidson and Richards (2005) reported little variation between deep impact and reference sites between 2000 and 2005. The exceptions were subtidal bedrock impact sites at Ngaruru and Arrowsmith which have much more macroalgae and support low densities of species that are more abundant at sites with little macroalgae. Data collected since 2005 confirms that, apart from Ngaruru and Arrowsmith, deep bedrock impact and reference sites were generally comparable. Furthermore, data supports the hypothesis that deeper sites are largely free from obvious ferry-induced impacts (Davidson and Richards, 2005, 2010 and present study).

5.2 Cobble-small boulder shores(intertidal)

The number of species and their density were sampled from two tidal heights from intertidal cobble-small boulder shores from March 1995 to March 2016. The data set provides a long-term description of species diversity and density at sites exposed to or located away from ferry wakes.

For reference sites at both tidal heights, the number of species and their density were variable, but usually within a range of values. On occasion, values stepped outside this range, but they always returned. The reason for these outlier events is unknown, but may be related to storms or prolonged periods or hot, stable weather combined with small tides resulting in mortality or invertebrate migration due to heat stress.

The number of species and the density of mobile molluscs from pooled reference low tide intertidal cobble shores steadily declined over the duration of the study. The reasons for this gradual decline are unknown, but may be attributable to wider environmental variables, global climate changes (e.g. ocean acidification, warming), other shipping activity or an impact due to sampling activity. The impact of ferry wakes could not be a factor given the locations of these reference sites away from the ferry route.

Number of invertebrate species and mollusc density (pooled data) were consistently higher at intertidal cobble reference sites compared to impact sites. These metrics increased markedly at both tidal heights at cobble-small boulder impact shores directly after the Bylaw was implemented and continued to increase or level out thereafter. A similar change was not observed at the reference sites. These data suggest intertidal cobble-small boulder communities prior to the Bylaw had been adversely affected by high speed ferry wakes.

Prior to the Bylaw, most cobble and small boulder substrata at impact sites were regularly overturned (Davidson 1995; Grange *et al*., 1995). For example, at Arrowsmith and Picton Point, regular strong wave action resulted in a jumbled, loosely packed intertidal shore, more resembling the substrata on a braided river bed (i.e. clean, regularly moving, with little or no encrusting biota) (Plates 1 and 2). In these conditions, the biota living on and under cobbles was rare or absent. In contrast, reference site cobbles were usually stable and surrounded by finer substrata such as pebbles, broken shell and sand, with a variety of intertidal organisms inhabiting the reef.

Plate 1. Intertidal cobble shore located at Picton Point (1995). Note the jumbled clean cobbles and pink (and bleached white) coralline encrusted rocks originating from the adjacent subtidal shore

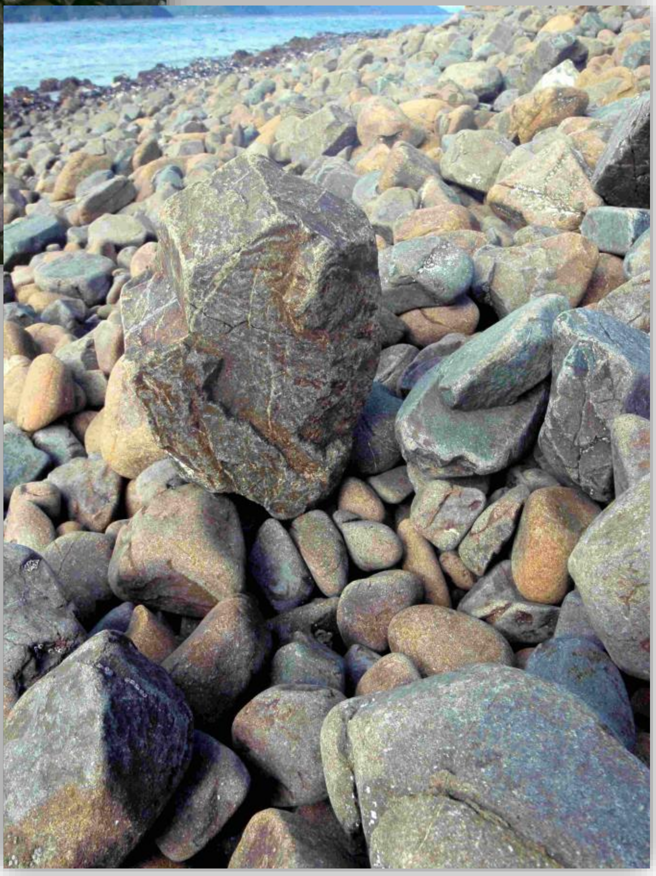

Plate 2. Intertidal mid-tide cobble shore, Picton Point (January 2010). Note the steep shore, jumbled clean appearance of cobbles, and absence of fine substrata such as sand, broken shell and pebbles.

Intertidal cobbles at reference sites were also disturbed by waves created by natural events such as storms and potentially by occasional passing ships. Storms create waves over sustained periods with higher energy compared to the normal range of conditions. These can move cobble and small boulder substratum as indicated by the presence of occasional pink coralline encrusted rocks well up into the intertidal zone. At impact sites, coralline covered rocks rolled up the shore by waves were a very regular occurrence prior to the introduction of the Bylaw (Plate 1). This phenomenon also occurred after the Bylaw and after higher speed ferries ceased operation, but at a reduced level (Plates 2 and 3).

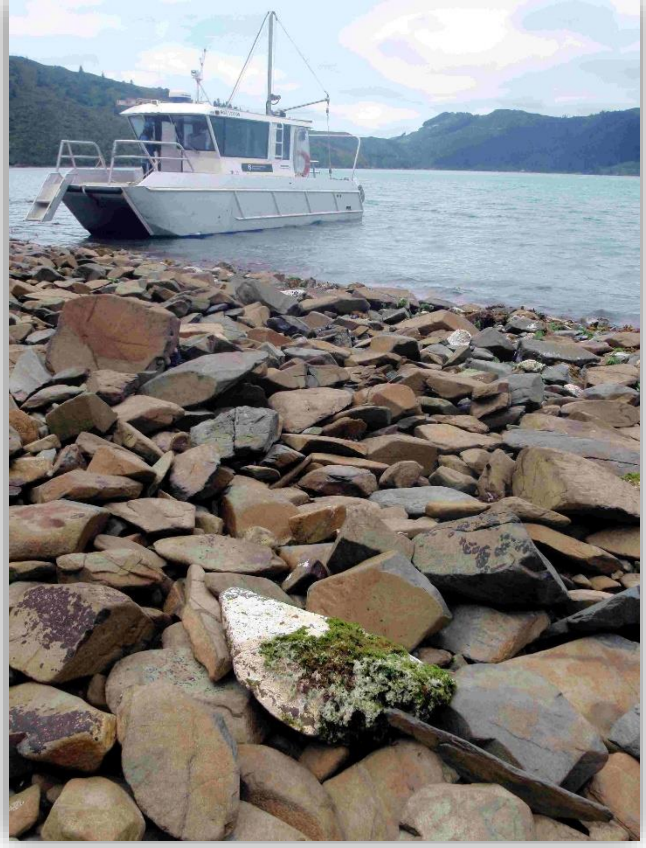

Plate 3. A coralline encrusted cobble from the subtidal zone relocated into the intertidal zone, Arrowsmith (January, 2010).

The principal difference between cobble-small boulder reference and impact shores was the frequency and scale of substratum disturbance (Grange *et al.*, 1995). Storm events occur periodically in the Marlborough Sounds and their impact will depend on duration, wind direction and fetch. In contrast, ferries pass through the Sounds multiple times each day and physical disturbance of moveable substrata by ferry wakes is regularly observed (Davidson and Richards, 2010).

Following the introduction of the Bylaw, waves produced by fast ferries were much smaller and less powerful, and there was a commensurate reduction in cobble and small boulder movement (Croad and Parnell, 2002). Reduced disturbance of substrata once the ferries slowed down is the most probable explanation for the increase in species metrics at some intertidal cobble-small boulder shores located along the ferry route. A comparable increase did not occur at reference sites where the number of species and their abundance generally remained within their normal range.

Although invertebrate species number and mollusc density increased at cobble-small boulder impact sites following the introduction of the Bylaw, these metrics remained consistently lower than at the reference sites. This continued disparity is likely due to the ongoing effects of waves produced by conventional ferries.

5.3 Cast animals

Subtidal (and low-tide) invertebrates may be cast up into the intertidal zone due to higher than normal wave intensity. During periods of increased wave energy such as storms, certain subtidal animals are cast onto the intertidal shore and those unable to migrate down the shore die. In the case of well-attached animals such as paua, they tend to be cast ashore still attached to rocks during high energy events. Few subtidal animals migrate into the intertidal or high tide drift line, leaving waves as the most probable explanation for this phenomenon.

Cast animal reference sites were spread over a relatively large area with a wide variety of shore aspects and fetch distances. Clark Point was the most outer and eastern 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 is also exposed to the predominant north-west wind and northerly storm events and often had the highest number of cast species and individuals for any reference site. Individual reference sites experienced some fluctuations presumably due to variability in storm effects. Pooled reference treatment data shows that the number of species washed ashore is relatively stable, with no major peaks or troughs.

In contrast, the number of cast species at impact sites often had elevated peaks compared to reference sites. The largest peaks were recorded prior to the Bylaw when fast ferries operated at high speed (Plates 5 and 6). Both Onapua and Te Weuweu impact sites have relatively small fetch distances and are sheltered from north-west winds. The impact site at Dieffenbach is exposed to the predominant north-west winds, but has a north-west fetch comparable to Clark Point, Double Bay and Blumine (north) and comparable values to these reference sites would be expected. The higher numbers of cast species and individuals from impact shores (individual sites and pooled data) is best explained by increased wave energies created by fast and conventional ferries (Plate 4).

The number of invertebrates cast ashore at impact sites was highest at the beginning of the study but declined after the initial months of fast ferry operation. Fast ferries continued to operate at high speed over this period so this decline in numbers of cast animals probably reflects a corresponding decline in the numbers of animals living in the shallow subtidal zone. Following the introduction of the Bylaw, the higher numbers of cast species and individuals recorded previously at impact sites were not repeated. Peaks at impact sites above reference levels occurred after the Bylaw, but their magnitudes were much lower than those recorded immediately after the arrival of the fast ferries.

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

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).

5.4 Cobble-small boulder (subtidal)

The abundance of kina at the outer and eastern-most reference sites (i.e. Clark Point and Long Island) was always highest and the most variable compared to the other three reference sites located further into Queen Charlotte Sound. These inner sites supported lower kina densities and lower levels of variability. This pattern of abundance may be related to environmental factors such as exposure and food availability, with edible turfing macroalgae (i.e. sea lettuce) present at Clark Point and Long Island compared to the inner three sites.

Apart from at Dieffenbach, kina densities at impact sites prior to the Bylaw were relatively low compared to Long Island and Clark Point. Dieffenbach had comparable numbers to the inner reference sites. 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. Apart from a peak at Clark Point in March 2012, no corresponding increase occurred at reference sites suggesting that the observed increase in kina abundance at these two impact sites was likely in response to reduced fast ferry wakes. It is unclear why the other impact sites did not show an increase in kina abundance. Since 2004, kina abundance at four higher density sites (two impact sites, Onapua and Monkey Bay; and two reference sites, Long Island and Clark Point) fluctuated in a roughly similar pattern, suggesting natural environmental factors also influenced kina abundance.

The lack of a recovery at Te Weuweu and Arrowsmith may have been due to the higher densities of large brown seaweeds which is not favoured by kina. Konar and Estes (2003) hypothesised that kelp stands can defend themselves from urchins by combining their flexible morphology with the energy of wave-generated surge. The lack of a recovery at Dieffenbach is puzzling because this site has little or no macroalgae and theoretically should support higher kina densities. Low numbers may be related to an absence of deeper cobble substratum (i.e. dominated by sand). A lack of deep cobbles may mean that shallow kina that are impacted by conventional ferry wakes are not replenished from adjacent deep habitats free of ferry impacts.

A range of cats-eye densities were recorded at individual reference sites, but each site often remained relatively consistent over the duration of the study. In contrast to the abundance pattern recorded for kina, cats-eye snails were least abundant at the two eastern-most reference sites (i.e. Clark Point and Long Island) compared to the three inner Sounds sites. At impact sites, large density peaks were recorded early in the study but by November 2000, snail density had declined to very low levels. After the Bylaw, cats-eye numbers increased at most impact sites to levels at, or above reference levels. Pooled impact site data followed a similar pattern, with snail densities increasing steadily following the bylaw's introduction before levelling out over the last decade. This pattern suggests the reduction of wave energy resulting from the ferry wake bylaw contributed to this species' recovery. Steady numbers of cats-eyes over recent years and at overall levels above those recorded at the reference sites suggests a moderate level of wave exposure from conventional ferries may be 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 are available.

Why very high numbers of cats-eye were recorded in the first two years of the study and may be related to the ability of this species to survive disturbance. Divers observed large numbers of cats-eye snails on the seabed that appeared to have been rolled into areas where they accumulated in unusually high numbers. Eventually these individuals may have died or been cast into the intertidal zone.

Paua were uncommon, rare or absent at all study sites apart from reference site at Clark Point. Clark Point supported relatively high densities in most years compared to both impact and other reference sites, though a decline in paua numbers occurred from 2008 onwards. The reason for their higher abundance at Clark Point is probably related to the presence of an abundant 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 suggesting wave energy may not be the main driver affecting paua densities along the ferry route.

5.5 Bedrock (intertidal)

The number of "detachable" intertidal mollusc species at some bedrock reference sites declined between the start and end of the study; this decline was most obvious when data were pooled. The number of species from the impact treatment varied, but finished close to where it started, suggesting the Bylaw had little overall effect on the number of bedrock intertidal mollusc species. The reason for the decline at the reference sites is unknown, but was presumably due to wider environmental factors.

Of note was the low range of mobile mollusc 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 reference rock faces (i.e. Blumine south and Kurakura). Observations of ferry wakes hitting these vertical walls (R J Davidson pers. obs.) suggest they have a greater physical impact than those arriving at more gentle sloping shores like Monkey Bay and to a lesser extent, Arrowsmith where wave energy is dissipated to an extent through wave run-up and higher numbers of species were usually recorded. These between-site comparisons suggest ferry wakes may be continuing to have an adverse effect on intertidal molluscs, particularly those inhabiting near-vertical rock faces.

Initially, the density of “detachable” intertidal bedrock species increased for several consecutive samples at both reference and impact sites, peaking in 2005 and 2006 respectively, before declining and stabilising over the last decade. These general patterns suggest wider environmental factors have influenced mollusc densities at both treatments. Nevertheless, pooled density consistently remained much higher at the reference compared to the impact treatment, and densities remained elevated at pooled impact sites compared to the levels recorded at the beginning of the study. These results indicate that mobile molluscs have partially recovered at intertidal bedrock shores along the ferry route following the Bylaw’s introduction, but ongoing wakes from conventional ferries may be limiting the extent of this recovery even though their effects appear less than those from unrestricted fast ferries. Some impact sites supported densities close to some reference sites, suggesting conventional ferry wakes reduce mobile mollusc species abundance at some but not all bedrock shores.

The density of intertidal “detachable” invertebrates from reference sites was highest from the three north-facing sites of Umuwheke, Double Bay and Snake Point. Similarly, north-facing impact sites (Monkey Bay, Kahikatea) supported highest densities of molluscs but densities were generally lower than at the reference sites. These data also support the hypothesis that ferry wakes continue to suppress mollusc densities at certain intertidal bedrock shores along the ferry route.

At intertidal bedrock impact sites, the density of the two most abundant mollusc species (i.e. oyster borer (*Lepsiella scobina*) and top-shell (*Melagraphia aethiops*) were generally well below those recorded from reference sites suggesting that fast and conventional ferry wakes have had, and conventional ferries still have, an impact on their abundance. There were some similarities between pooled impact and reference treatments, with similar though slightly out of sync patterns in their abundance. These similarities between pooled impact and reference treatments suggest wider environmental factors are also having an influence on the abundance of these two species.

Intertidal bedrock cats-eye densities were highly variable at reference and impact sites with peaks and troughs recorded throughout the study. Cats-eyes can be patchy in their distribution, most often restricted to crevices and shady positions at and close to low tide. This variability makes cats-eye snail a poor candidate for monitoring ferry wakes as any changes are likely to be masked by the high natural variability.

5.6 Subtidal bedrock shores (1.5–2 m depth)

The number of target species at deep subtidal bedrock shores was higher, lower or little different between pooled reference sites and impact sites. In most cases when values were different, the abundance values followed comparable patterns, suggesting ferry wakes have little influence and environmental factors are more important at these water depths.

Turbulence from ferry wakes was observed by divers at 1.5 – 2 metres, but was much less compared to shallower depths. Divers could maintain their position at depth, but were often rolled or overturned in the shallows, especially by fast ferry wakes.

Data have been collected for 17 years which has established temporal and spatial trends for deep subtidal bedrock sites. Continued monitoring of deep strata is therefore no longer necessary.

5.7 Subtidal bedrock shores (0-0.5 m depth)

The number of species recorded from shallow subtidal bedrock reference sites largely remained stable throughout the duration of the study, and at combined levels mostly above those documented at impact sites. In contrast, the number of species at almost all impact sites increased after the Bylaw from initial low levels. The number of species at the pooled impact treatment increased for six years peaking in February 2006. High levels were also recorded in March 2017 when the mean number of species at impact sites came close to reference levels. These data suggest unrestricted fast ferries had reduced the number of species at shallow subtidal bedrock sites exposed to ferry wakes, and that there was a recovery following the introduction of the Bylaw. The conventional ferries may still be having a level of impact on shallow subtidal bedrock species diversity, as evidenced from the recorded differences between impact and reference sites.

The density of shallow subtidal bedrock species at impact sites (combined and at most individual sites) increased from a low in November 2000 through to peaks in February 2006 and February 2008. Since that time, densities declined at the two impact sites that supported the highest numbers of invertebrates, though mean pooled abundance at impacts sites mostly remained above reference levels over the last several years. These data suggest unrestricted fast ferries had a large impact on shallow subtidal species abundance; however, conventional ferries appear to have little or no negative impact and at some sites may contribute to an increase in the abundance of some species.

Both kina (Plate 7) and cats-eye densities at shallow subtidal impact sites exhibited initial low densities followed by a generally consistent increase for several years after the Bylaw to reach levels above those recorded at the pooled reference treatment. For these species, densities have remained at or higher than those recorded for the reference treatment suggesting they are not adversely affected by conventional ferries.

Black-foot paua were present in very low densities and their abundance varied considerably between sample events. A small increase may have occurred at some impact sites, but numbers were so low and variable it is difficult to be conclusive. Based on their low abundance combined with the between-year variability, no conclusions in relation to ferry impacts are possible for paua.

Plate 7. Kina located at a shallow subtidal bedrock site at Kahikitea (March 2013).

6.0 Conclusions

When fast ferries first arrived in the summer of 1994-1995, many Marlborough Sounds residents commented on a large and often dramatic increase in wave size. Locals also reported invertebrates being washed ashore and argued that unrestricted fast ferries were having an adverse impact on biological communities in the sheltered shores of Tory Channel and Queen Charlotte Sound. The Marlborough District Council implemented a navigational Bylaw in late 2000 which restricted ferry speeds and introduced a “wash rule” for managing the effects of ferry wakes.

The present study builds on previous studies aimed at investigating the recovery of biological communities at intertidal cobble-small boulder, bedrock and shallow subtidal shores along the ferry route following the introduction of the 2000 Bylaw (Table 2). Various biological metrics were monitored at several impact and comparable reference sites over the course of the 22-year study, including species diversity and abundance of various target species, individually and collectively. Table 2 provides a high-level summary of the monitoring results for each shore type.

There was variability in responses between species, species groups, locations, substrata and tidal heights. Nevertheless, species diversity and the abundance of certain species generally increased at impact sites for several years following the Bylaw’s introduction. Similar increases were not replicated at reference sites. In some cases, the scale of the recovery at impact sites following the Bylaw was large; for example, at some shallow subtidal bedrock sites, the abundance of invertebrates increased above values recorded from reference sites. At no time prior to the Bylaw speed restriction did intertidal and shallow subtidal shores support more species or higher densities than at reference sites and in most cases dramatically lower numbers were found.

No biological monitoring data are available for the period before fast ferries were operating. Nevertheless, the large differences between impact and reference sites before the Bylaw was implemented and the subsequent recovery of marine life, strongly suggest fast ferries operating at unrestricted speeds caused significant adverse impacts on intertidal and shallow subtidal marine communities.

For intertidal cobble-small boulder shores, the magnitude of the impact from unrestricted fast ferry operation was large. At these shores, the number of species and their abundance were severely reduced. There is no other plausible explanation for the recorded recovery other than the slowing of fast ferries to below 18 knots

After the speed Bylaw was implemented, a recovery occurred at most, but not all sites. In the absence of any ferries, recovery should theoretically continue until impact sites support biological communities comparable to those recorded at reference sites (Table 2). Such a recovery may not always be possible due to natural differences between sites including Tory Channel's unique hydrodynamic regime and the presence or absence of macroalgae beds. Nevertheless, the weight of evidence is that conventional ferries continued to affect and suppress the recovery of some species at certain locations and tidal heights.

Of further interest is that the recovery of some species metrics levelled out or sometimes declined after about 2005 or 2006. This coincided with the introduction of the Kaitaki in late 2005.

Continued monitoring of shoreline communities would ensure any future changes in the Cook Strait ferry fleet (e.g. speeds and vessels) can be assessed properly. The following amendments to the programme are recommended:

1. Reducing sampling intensity to every second summer (given the current long-term data set and the amount of variation which has been detected);
2. Terminating deep subtidal bedrock monitoring.
3. Establishing two new intertidal cobble shore monitoring sites between Monkey and Dieffenbach Point to account for existing between-site variability.

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

Shore type	Biological feature	Fast ferry impacts	Effect of Bylaw	Conventional ferry impacts	Status 2017
Cobble (intertidal)	Species	Yes	Increase (most sites)	Yes	Stable but below control
Cobble (intertidal)	Mollusc density	Yes	Increase (some sites)	Yes	Variable but below control
Cobble (intertidal)	Cast invertebrates	Yes	Lower peaks	Yes (periodic)	Stable, occasional small peaks
Cobble (subtidal)	Kina	Yes	Increase (most sites)	Minor	Stable
Cobble (subtidal)	Cats-eye	Yes	Increase	No	Stable
Cobble (subtidal)	Paua	Unknown	No	Unknown	Uncommon
Bedrock (intertidal)	Diversity	Yes (at some sites)	No	No	Stable
Bedrock (intertidal)	Density	Yes	Increase (some sites)	Yes	Stable
Bedrock (deep subtidal)	Diversity and abundance	No	No	No	Stable
Bedrock (shallow subtidal)	Number of species	Yes	Increase (most sites)	Some sites	Small decreases and some increases
Bedrock (shallow subtidal)	Density	Yes	Increase (most sites)	No	Stable
Bedrock (shallow subtidal)	Kina density	Yes	Increase (most sites)	No	Stable
Bedrock (shallow subtidal)	Cats eye	Yes	Increase (most sites)	No	Stable
Bedrock (shallow subtidal)	Black-foot paua	Unknown	Small increase	Unlikely	Low abundance, variable, increasing?

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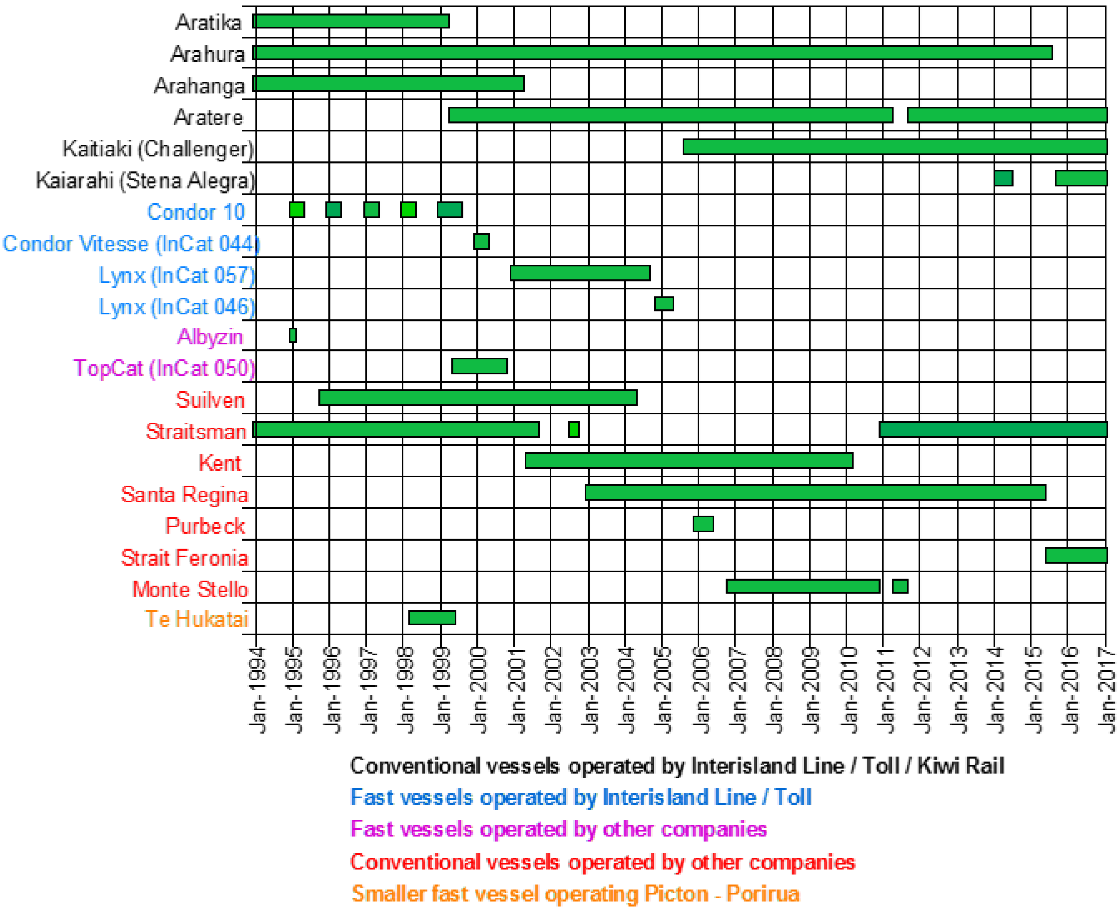
Appendix 1. Operational periods for ferries from 1994 to 2017.



Notes: 1) The ‘Straitsman’ that commenced operation in December 2010 is a different vessel operating under the same name. 2) The Monte Stello was operated by the Interisland Line between April and September 2011.