Distribution of invasive plant species in the sand dunes of Kaitorete Spit, Canterbury

Prepared for the Department of Conservation, Mahaanui District

By

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18 April 2016

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Cover Photo: Marram grass establishing from sea-dispersed rhizomes near Birdlings Flat, Kaitorete Spit (October 2015).

Summary

This report updates the distribution of exotic plant species in the sand dunes of Kaitorete Spit. It has been 10 years since the first survey of tree lupin, marram grass, iceplant, gorse, boxthorn and pine (Hilton *et al.* 2006a). The Department of Conservation has been active in managing these species on the Spit, along with several other non-native plant species since this report. The location of these six species plus four others considered to threaten the conservation values of the Kaitorete dunes (horned poppy, Californian poppy, purple groundsel and broom) were mapped using field surveys in October 2015, supplemented by aerial photographs. Changes in species distributions since 2005 are reported, and the efficacy of DOC weed control works evaluated. Recommendations for the future control of the target species are provided.

The target weed species were found the length of the Spit, but were, in general, more common in the western half of the Spit and near Birdlings Flat. The cover of the target weed species remains relatively sparse, with plant communities dominated by indigenous dune species. Lupin is the only surveyed species to have formed a semi-continuous cover over a large portion of the Spit. The remaining target weed species were typically found as small populations and isolated individuals. Many of the surveyed species, however, showed signs of active invasion and range expansion. The DOC control works over the past decade have probably been critical in maintaining the relatively low levels of weed invasion at Kaitorete.

The density and distribution of most of the weed species examined in the present study has declined since 2005. Significant populations of most species still remain, largely due to persistent and long-lived seed banks and non-controlled populations that serve as a source of propagules. All of the weed species examined in the current study remain a priority for control, but future control programmes can be designed to target multiple species because of the overall sparseness of the weed species along most of the Spit. Finally, it is recommended that that regular and systematic monitoring be implemented to measure the effectiveness of the operations in removing target weed species, as well as the recovery of desired ecological and geomorphic properties.

Contents

1.0 Introduction

Coastal sand dunes are one of New Zealand's most vulnerable natural environments. Grazing, afforestation and infrastructure development on coastal dunes since the late 1880s, combined with the spread of a wide range of exotic plant species, have contributed to a rapid decline in extent and naturalness of New Zealand's coastal sand dunes (Hilton 2006). The area of sand dune now is less than 30% of its extent in 1950, and most of the remaining dune systems have lost geomorphic function and associated biodiversity (Hilton *et al.* 2000, Hilton 2006). Sand dunes retaining native vegetation communities are rare, and much of the flora and fauna of dune environment is considered to be threatened. There is a strong imperative, therefore, to protect and conserve the few dune systems that retain significant conservation values.

Kaitorete Spit is an approximately 28km-long mixed sand and gravel prograded barrier separating Lake Ellesmere (Te Waihora) from the Pacific Ocean (Figure 1). The focus of this study, the active dune system, extends alongshore for about 25km, but is relatively narrow – extending only up to 220m inland. Overall it covers an area of 461ha – making this one of the largest dune systems in New Zealand. The dunes are well defined in the first aerial photographs (1947), and may have been very active in the early part of the 20th Century. Earlier phases of dune mobility extend up to 1100m inland, but these have been largely converted to pasture and retain relatively few conservation values. For the purposes of this report 'the Kaitorete dunes', the 'dune system' or the 'active dunes' refers only to the narrow strip of dunes formed during the most recent phase of dune mobility (as identified in Figure 1). The Kaitorete dunes are primarily public conservation land administered by the Department of Conservation (DOC). Over 80% of the dunes are contained within a series of reserves and conservation areas along the seaward margin of the Spit (Figure 1).

The eastern half of the Spit is stable or slowly prograding (building seawards), while the western half is erosional with frequent blowouts. Dune forms comprise foredunes, deflation surfaces and depositional elements associated with formally active parabolic dunes, but that are now largely stable (Figure 2). Distinct plant communities are associated with these landforms (Widodo 1997, Konlechner 2015). Plant communities in the foredune environment, where salinity and aeolian sedimentation is relatively high, are dominated by pīngao *(Ficinia spiralis)*. Dominant species in the deflation surfaces behind the foredune include the native cushion plant *Raoulia australis,* with other native dune species including pīngao, *Carex arenaria*, and *Scleranthus uniflorus* also present. The backdune environment, comprising the trailing arms and depositional lobes of stable parabolic dunes, contains the highest diversity of species including isolated populations of *Muehlenbeckia complexa* and *Pteridium esculentum* with widespread pīngao. Several non-native European grasses (*Holcus lanatus*, *Dactylis glomerata*, *Bromus mollis*) and forb species are widespread through all three environments. These non-native species are of pastoral origin and have probably self-

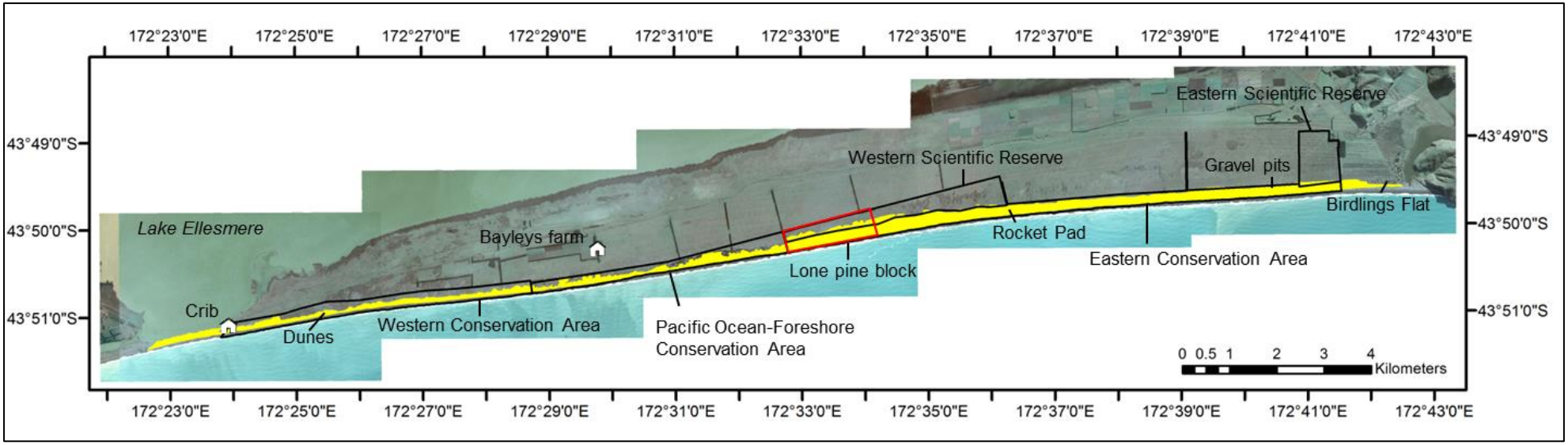

Figure 1. Features of Kaitorete Spit referred to in the present report. The active dune system is outlined in yellow. Public conservation land administered by the Department of Conservation is outlined in black.

introduced to the dunes at Kaitorete Spit from the surrounding farmlands. The Mediterranean grass, *Lagurus ovatus*, is also widespread.

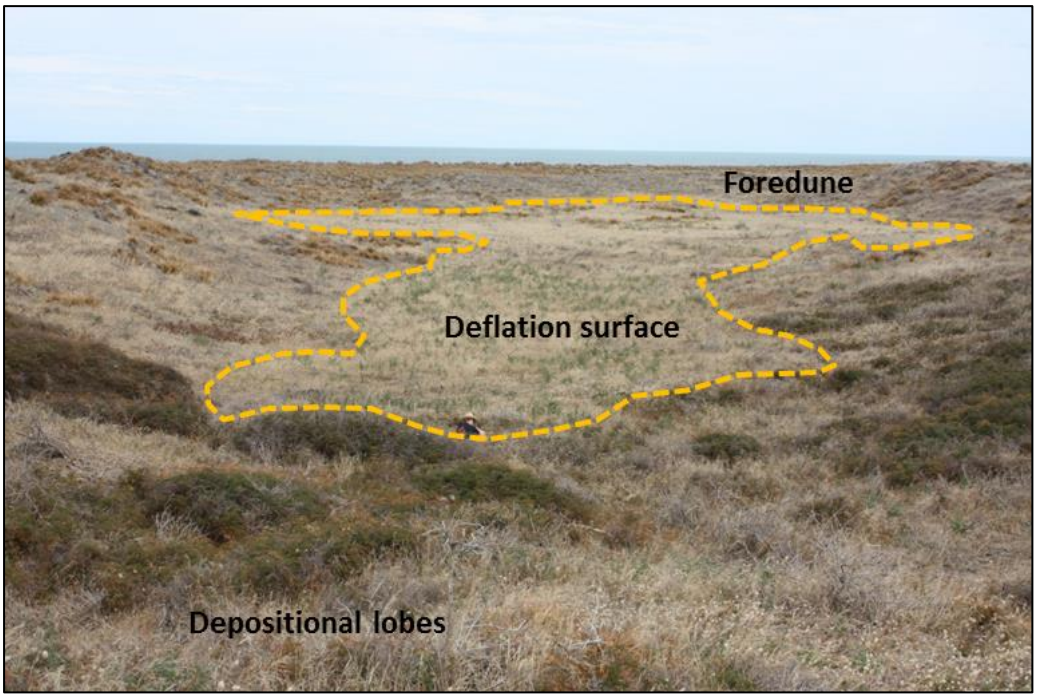

Figure 2. The dominant dune landforms present at Kaitorete Spit. The photograph was taken looking down the long axis of the parabolic dune (i.e. the direction of dune migration is towards the photographer).

Exceptional conservation, landscape and geomorphic values are associated with the active dunes of Kaitorete Spit. It is one of only 53 dunes in New Zealand identified as being of national conservation significance, and the only dune system retaining significant (or arguably any) conservation values on the east coast of the South Island (Johnson 1992, Partridge 1992). Kaitorete Spit retains outstanding populations of indigenous dune flora and fauna. The population of pīngao, for example, is one of the largest in New Zealand, and the last extensive population on the east coast of the South Island (Hilton 2006). The Spit is a stronghold for a number of rare and locally endemic plants, most notably *Craspedia* "kaitorete", *Muehlenbeckia astonii* and *Carmichaelia appressa* (Davis 2002, Molloy *et al.* 1991), the last remaining population of the red katipo (*Latrodectus katipo*) in the South Island (Patrick 2002, Lettink and Patrick 2006), and provides habitat for at least four species of lizard and three species of skink (Lettink *et al.* 2008), and several shorebirds including banded dotterel (*Charadrius bicinctus*). The conservation values of Kaitorete Spit are reviewed in more detail by Davis (2002).

The values of the Kaitorete dunes remain, in large part, because of the low levels of weed invasion and the management of the Spit by the Department of Conservation. The sand dunes of Kaitorete Spit have, until quite recently, remained relatively free of exotic plant species capable of adversely affecting ecological and geomorphic function and community

structure. In particular, marram grass (*Ammophila arenaria*) is not as widespread or dominant compared to many other sites in the South Island (Hilton 2006). Tree lupin (*Lupinus arboreus*) has established since the early 1990s, over a wide area. Several other weeds of concern are also present, including boxthorn (*Lycium ferocissimum*), gorse (*Ulex europaeus*), pine (*Pinus radiata*), iceplant (*Carprobrotus edulis*) and horned poppy (*Glaucium flavum*).

Despite the sustained efforts of the Department exotic plants remain the main threat to the conservation values of Kaitorete Spit. This study documents the distribution of 10 exotic plant species considered to pose a major threat to the Kaitorete dune system. It updates the distribution of six species mapped in 2005 by Hilton *et al.* (2006a) (tree lupin, marram grass, iceplant, gorse, boxthorn and pine), and provides the first distribution maps of four other species (horned poppy, Californian poppy (*Eschscholzia californica*), purple groundsel (*Senecio elegans*), and broom (*Cytisus scoparius*). Changes in species distributions since 2005 are considered, and where appropriate the efficacy of the DOC weed works are evaluated. Recommendations for the future management of these species are provided.

2.0 Target plant species – ecology, impact and history of control at Kaitorete Spit

Hilton *et al.* (2006a) reported multiple occurrences of lupin, marram, iceplant, gorse, boxthorn and pine within the dunes at Kaitorete Spit. These species were, in general, more common across the western half of the Spit, relatively scarce in the east between the Rocket Pad and Birdlings Flat, with a second concentration at the Birdlings Flat village. DOC has been active in managing these species on the Spit, along with several other non-native plant species since this report.

Weed work within the sand dunes at Kaitorete Spit has been focused within the boundaries of the public conservation land, albeit control at the eastern end of the Spit usually extends beyond the conservation land to the Birdlings Flat village. Control work organised by DOC is conducted by city and regional council rangers, contractors, volunteers and DOC staff with different management strategies employed along the Spit depending on the number and density of target species. Local residents have also conducted some non-DOC organised weed control near Birdlings Flat. The invasive ecology and history of weed control at Kaitorete Spit specific to each of the target species is summarised in the following paragraphs.

Tree lupin

Tree lupin is a perennial shrub native to the southern and central coast of California (Pickart *et al. 2004*). Lupin is relatively short lived (<10 years) (Strong *et al.* 1995), but grows and matures rapidly producing large numbers of seeds in its second spring. Seed is dispersed from the plant by explosive pods over short distances (<10m) (Maron and Simms 1997), with secondary dispersal over longer distances facilitated by wind, water and biotic vectors. Lupin seed is long-lived and forms a large, persistent seed bank. Seed bank density within the upper 10cm of soil at Kaitorete has been measured at 120 viable seeds per m^2, and has the potential to remain viable for more than 40 years (Ghaemaghamy 2011).

Lupin alters the structure and chemistry of dunal soils through the accumulation of litter and release of organic nitrogen (Pickart *et al.* 1998); it facilitates the invasion of other non-native plant species (Reynolds *et al.* 2001); and it can decrease sand mobility allowing opportunistic non-native and native plant species to establish (Pickart *et al.* 2004). These impacts can, collectively, result in the conversion of sparsely-vegetated dunes, dominated by native plant species with a moderate-to-high tolerance of sand mobility, to stable, densely vegetated systems dominated by non-native plant species. The increased plant cover not only displaces the native dune flora, but also prevents some birds (e.g. dotterels) nesting and can increase the predation of birds by cats and mustelids.

It is unclear how lupin established on Kaitorete Spit. It was most likely deliberately introduced in conjunction with *Pinus radiata* in the 1950s or 1960s. Between 1989 and 2005 the area occupied by lupin increased rapidly from 17.5ha (3.8% of the total dune area) to 93ha (20% of the total dune area), and lupin was continuing to spread downwind of the main infestations (Hilton *et al.* 2006a). Over much of this range lupin formed a semi-continuous canopy, with associated loss of native dune flora.

Over the past decade the Department of Conservation has prioritised lupin control. The current programme of lupin control commenced in 2007 when herbicide was applied to a 39ha section of the dunes (the Lone Pine block, Figure 1) using a helicopter (see Hilton and Konlechner 2008, 2009 and Konlechner and Hilton 2010 for further details of this work). Over the intervening years the area subject to lupin control has been progressively expanded, and now encompasses most of the Spit. Control has occurred annually, typically in spring prior to seed pod development. The strategy has been to target mature plants to prevent further inputs of seed to the seedbank.

Different management strategies have been employed along the Spit, depending on the extent and density of lupin populations. The dunes between the Rocket Pad and Birdlings Flat have been grid-searched annually and any lupin present controlled. Purple groundsel, iceplant and gazania are also targeted during this search. Areas of lupin between the Rocket Pad and the western boundary of the Lone Pine block are controlled annually prior to plant maturation and seed dispersal. All plants are targeted. Contractors control large patches of

lupin through the ground-based application of herbicide, followed by a grid search by Christchurch City Council rangers, DOC staff and volunteers who search for missed plants and outlying populations. Occasional grid searches have also been conducted west of the Lone Pine block to the crib, which marks the approximate boundary of the DOC managed conservation land at the western end of the spit, but these searches have typically targeted weed species other than lupin. Areas of dense lupin, west of the Lone Pine block, have been controlled largely through the application of herbicide by helicopter with small patches and outlying plants managed through the ground-based application of herbicide.

Marram grass

Marram grass is a perennial grass native to the temperate coast of Europe (Huiskes 1979). This plant is a primary colonising species on mobile dune systems and is able to withstand substantial burial by sand. Marram is a significant weed of coastal dunes in New Zealand and is associated with the modification of the geomorphic processes and the displacement of the indigenous flora. Marram forms foredunes that are higher, steeper and potentially much more stable than foredunes formed by New Zealand's indigenous dune plants (Esler 1970). It out-competes and displaces the indigenous flora in most circumstances (Partridge 1995, Hilton *et al.* 2005, Hilton 2006). It stabilises transgressive dune-systems, (which promotes succession) and facilitates the invasion of other, less burial-tolerant, weedy species (Hilton 2006, Hilton *et al.* 2006b). It forms a dense grassland, in contrast to the sparsely vegetated character of the unmodified dune-systems; and can result in the progradation of foredunes so that dune erosion is more frequent and habitat for shore birds is reduced (Moore and Davis 2004, Hilton *et al.* 2006b).

Marram expands its range both vegetatively (through the lateral extension of rhizomes) and through seed dispersal by wind. The dispersal of rhizomes in the sea facilitates the spread of marram along shorelines (Konlechner and Hilton 2009). Regeneration after control occurs via vigorous re-sprouting from dormant buds contained on the rhizomes (the bud-bank) (Hilton and Konlechner 2010), and in some cases from a long-lived seed-bank (Konlechner and Hilton 2010). The ability of marram to spread both vegetatively and via seed usually results in the rapid invasion of dunes in New Zealand (Hilton *et al.* 2005, Hilton 2006); however the rate of spread of marram at Kaitorete is unclear. Marram establishes within the strandline at Kaitorete Spit from sea-dispersed rhizomes, but its subsequent spread is relatively slow. Nonetheless, by 2005 the ongoing establishment and spread of marram at Kaitorete had resulted in numerous small colonies scattered along the length of the Spit (Hilton *et al.* 2006a).

Marram grass has been controlled intermittently at Kaitorete Spit since the late 1990s. Between 2006 and 2010 all known populations on the back-beach between Birdlings Flat village and the crib were treated annually with a grass-specific herbicide (Gallant-NF/Ultra) and up-take oil. Known populations further inland were also controlled. New populations of

marram have been exposed as the lupin control programme has progressed, and since 2010 marram control has only occurred at irregular intervals. Control is planned for the 2016/2017 financial year.

Iceplant

Iceplant is a mat-forming perennial herb native to South Africa. It is not as tolerant of burial by sand as marram grass; but, iceplant is also a primary coloniser of mobile dunes in some situations. Iceplant establishes from both vegetative fragments and from seed. Seed is dispersed by mammals (e.g. rats and rabbits), and can remain viable for at least two years in the soil (D'Antonio 1990, Bourgeois *et al.* 2005). Once iceplant becomes established, it exhibits a high rate of vegetative reproduction, and may rapidly form impenetrable mats over 50m wide and 50cm deep (D'Antonio and Mahall 1991, D'Antonio 1993). Iceplant in dunal soils is extremely competitive, displacing native dune flora (D'Antonio and Mahall 1991, D'Antonio 1993). It alters soil pH and influences nutrient dynamics (D'Antonio 1990, D'Antonio and Mahall 1991), and can hybridise with related species in many parts of its introduced range, including New Zealand (Chinnock 1972, Albert *et al.* 1997, Suehs *et al.* 2004). Iceplant at Kaitorete Spit is controlled annually using either manual removal or herbicide. Control has been focused at the eastern end of the Spit near Birdlings Flat, with some control of larger plants further west.

Gorse

A fast growing perennial shrub, gorse is a significant weed in stable dune environments. It produces large amounts of long-live seed and it is capable of rapid growth and colonisation. Seed is dispersed from the plant by explosive pods over short distances (<4m) (Hill *et al.* 1996), with secondary dispersal over longer distances by wind, water and biotic vectors. Gorse in dunal soils is extremely competitive, displacing native dune flora and altering soil conditions (Egunjobi 1969, Grubb and Suter 1970). Gorse at Kaitorete is concentrated at the western end of the Spit, but small scattered populations occur the length of the Spit (Hilton *et al.* 2006a). Regular control, targeting known populations, has occurred since 2003, with some control conducted prior to that.

Boxthorn

Boxthorn is a fast growing perennial shrub native to South Africa. It is a significant weed of dune environments. Boxthorn is capable of rapid growth and colonisation but does not flower or produce seed until it is at least two years old. It forms dense, tall, long-lived stands, excluding most other vegetation and can negatively affect nesting sites of native birds. Spread is almost always by seed dispersed primary by birds and mammals (Fuller 1998), but it has also been known to establish from dislodged stem or root fragments (Noble and Rose 2013). Boxthorn produces large amounts of seeds; however, there is little

documented information available about how long the seeds remain viable (Noble and Rose 2013). Some studies indicate seed-bank persistence is short, perhaps lasting only days to one year (Department of Parks and Wildlife, 2016). Others report a persistent seed bank, of unknown longevity.

Boxthorn is present throughout the dunes at Kaitorete, but becomes less common towards Birdlings Flat (Hilton *et al.* 2006a). DOC has undertaken intermittent control of boxthorn between the Lone Pine block and the crib since 2002, but this species is not currently a priority for weed control.

Pine

Pine is a fast growing softwood tree able to colonise sparsely-vegetated but relatively stable dune soils. This species out-competes and suppresses native vegetation (Harding 2001) and can alter nutrient and water regimes (Harding 2001, Richardson 1998). Pine seed is dispersed by wind, with pine able to rapidly colonise large areas as the result of one significant dispersal event (Harding 2001). Some spread can also occur by biotic agents. Pine was deliberately introduced to the Kaitorete Spit dunes west of the Lone Pine block, and has spread from these plantings. Control of pine commenced in 2004. Initial control targeted trees at the western boundary of the Bayley property and has progressively expanded to the east. Control has occurred annually between 2004 and 2009 and then every 3 years. Pine control to date has targeted large trees with only occasional control of new seedlings and saplings.

Horned Poppy

Horned poppy is an annual or short-lived perennial herb that produces large amounts of viable seed (Scott 1963). Plants can produce flowers in the first year, but most perennial plants flower for the first time in their second year (Solås *et al.* 2004). Seed dispersal is ballistic, by wind, and (over relatively short distances) in the sea (Scott 1963, Solås *et al.* 2004). Annual control of horned poppy occurred between 2004 and 2013 at Kaitorete Spit, with intermittent control since then.

Californian Poppy

Californian poppy is an annual or short-lived perennial herb with a distinctive orange-yellow flower. Plants can flower in their first year producing large amounts of seed (Cook 1962). Primary seed dispersal is ballistic; with spread by biotic agents (grazing animals) also possible (Pena-Gomez and Bustamante 2012). The seed is relatively short-lived (<5 years), but it germinates readily in high light, disturbed environments (Montalvo *et al.* 2002). Only two plants of Californian poppy have been found in the Kaitorete dunes since 2003.

Purple Groundsel

Purple groundsel is an annual herb native to South Africa. It spreads rapidly in sand dune habitats, displacing native dune vegetation. Seed is largely wind-dispersed but can also be dispersed by water and biotic factors (Surf Coast Shire 2010). Purple groundsel has a long flowering season with seed produced between August and May. Control of purple groundsel at Kaitorete commenced in 2004 and since 2006 control has occurred four times annually because of the long flowering season.

Broom

Broom is a fast-growing perennial shrub, and is a significant weed in stable dune environments. It produces large amounts of long-lived seed and it is capable of rapid growth and colonisation. Seed is dispersed from the plant by explosive pods with secondary dispersal over longer distances facilitated by water and biotic vectors (Hoshovsky 1986). Broom displaces the indigenous flora, negatively affects habitat suitability for animal species including many birds and insects, and alters soil conditions by fixing nitrogen (Timmins and MacKenzie 1995). Broom has been controlled at Kaitorete since 2004, usually in conjunction with lupin control.

3.0 Methodology

The target species were mapped using ground-based field surveys supplemented by aerial photographs. Ground surveys were undertaken the length of Kaitorete Spit from the western boundary of the Birdlings Flat village to the crib. Plants were surveyed from the back of the beach to the inland extent of the DOC-managed conservation land, albeit the Eastern Scientific Reserve was not surveyed in either the current or 2006 study. The foreshore in front of the village to the outlet of Lake Forsyth was not surveyed systematically, but the presence of any of the target species was noted. Marram grass and iceplant form a dense cover at the western end of the Spit, between the crib and the outlet of Lake Ellesmere. The presence of the other target species here was also noted.

Ground surveys were conducted over a five day period (28^{th} – 30^{th} October, 2015) by four people walking a series of parallel lines. Figure 3 shows the density of the search across the Spit. The search intensity varied depending on the topography and the visual catchment. In general, the search pattern near the foreshore, where the dunes are relatively high and complex, was more intense compared with the more open topography near the rear of the dune system. The search pattern was also more intense in the eastern half of the Spit, where the target species are much less abundant and occupy a small area where they do occur, compared to the larger and more obvious infestations in the western half of the Spit.

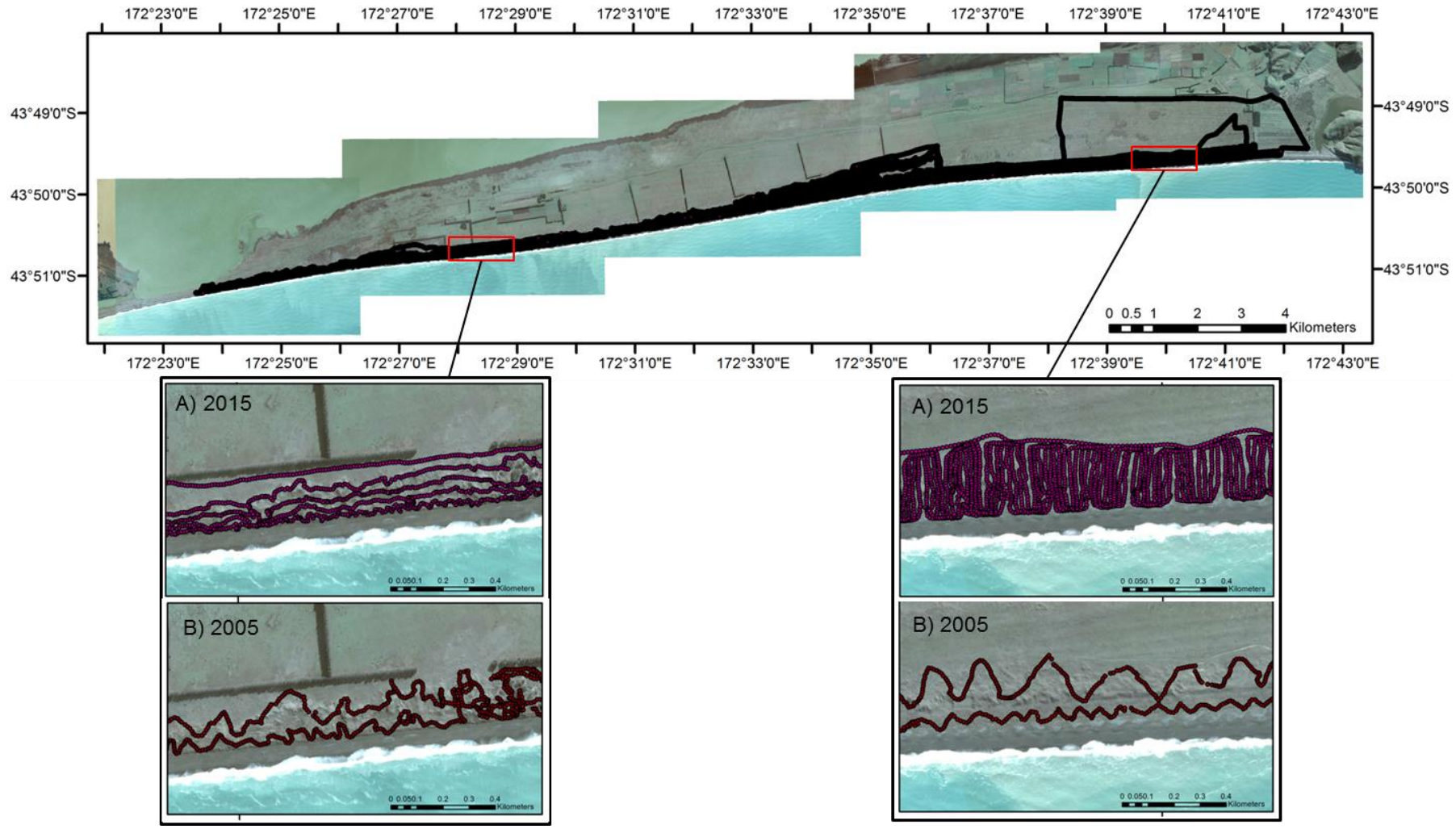

Figure 3. The intensity of search effort across the Spit as recorded by GPS tracks. Insets show the difference in search intensity between the survey conducted during A) the present study in 2015, and B) Hilton *et al.* (2006a) in 2005.

The target exotics were recorded using Garmin handheld GPS units with a horizontal accuracy during the survey of 3-5m. Each species was recorded differently, due to differences in distribution, density, growth habit (e.g. clonal vs. shrub), and history of control. These are detailed as follows.

East of the Rocket Pad all individual plants of lupin were recorded, as the density of lupin here is low and lupin typically occurs as single plants or small colonies (<10 plants). West of the Rocket Pad weed management over the last decade has resulted in a mosaic of large, semi-continuous areas of relatively sparse mature lupin and/or regenerating seedlings, smaller patches of dense mature lupin, and isolated plants. The location of all isolated individuals was recorded, whereas larger populations where these species formed a semi-continuous cover were recorded by walking the perimeter of the infestation and estimating the density of plants. Finally, much of the lupin recorded between the Lone Pine block and the Rocket Pad occurred as patches of seedlings less than 30cm in height. In this block we differentiated between mature and recently established seedlings.

The location of all isolated plants and small colonies of marram grass and iceplant between the crib and Birdlings Flat were recorded as single waypoints. Larger colonies (>5m^2 in area) were recorded by walking the perimeter of the colony and estimating plant density. Occurrences of marram grass at the western end of the Spit, between the crib and the outlet of Lake Ellesmere, were mapped from 2015 satellite photography.

Most of the live pine we observed occurred as regenerating trees that had survived control or as seedlings and saplings obscured by dead pine material. Accessible plants were recorded as single waypoints, but given the density of the dead pine material this was only a small proportion of the total amount of living pine. Our maps therefore indicate the distribution of pine within the dunes the Spit, but do not accurately show density.

Isolated plants of boxthorn, horned poppy, Californian poppy, broom and purple groundsel were recorded as single waypoints. Larger populations where these species formed a semi-continuous cover were recorded by walking the perimeter of the infestation and estimating the density of plants.

Target species were mapped using ArcGIS using our data and the data collected in 2005 by Hilton *et al.* (2006a). The base map consists of satellite imagery from 2015 and was sourced from GoogleEarthPro.

There were differences between the two surveys which limited our ability to directly compare species distributions between 2005 and 2015. The Hilton *et al.* (2006a) survey was conducted by two people, compared to four in the current study, which resulted in a lower search effort in 2005 (Figure 3). We examined the 2005 search tracks, where we found plants or colonies in 2015 that were not present in 2005, to determine whether these plants were in fact new occurrences (i.e. dispersed and established since 2005 indicating

population expansion), or had simply not been recorded during the 2005 survey. If the 2005 search tracks pass some distance (>20m) from the location of the plants recorded in 2015 then this indicates that these plants may have been present in 2005. If however, the 2005 search tracks passed close to or over the location of the plant recorded in 2015 then this indicates establishment since 2005. In addition, in contrast to Hilton *et al.* (2006a), we only recorded live plants. Some species, such as boxthorn, can defoliate in response to salt stress giving the impression of plant necrosis. We observed no such plants during the 2015 survey.

4.0 Results

The results of the survey of the target species are mapped in Appendix A and B. Appendix A presents the location of each target species along the length of the Spit in 2015 and, where appropriate, in 2005. The surveyed location of all weed species along the Spit is mapped at a finer scale in Appendix B. The following paragraphs should be read in conjunction with the figures presented in both appendices.

Lupin is the only surveyed species to have formed a semi-continuous cover over a large portion of the Spit. The remaining species are typically found as small populations of a few plants and isolated individuals, and do not yet dominate plant communities over large areas. The target weed species were found the length of the Spit, but in general are more common west of the Lone Pine block and near Birdlings Flat.

Tree lupin

The distribution of lupin in 2015 remains similar to that recorded in 2005. Most lupin occurs within a 10km length of the coast between the Western Conservation Area and the Rocket Pad, with a second smaller concentration of lupin at the western end of the Spit. A scatter of plants was observed between the Rocket Pad and Birdlings Flat. The following paragraphs describe changes to the distribution and density of lupin along the Spit since 2005 from west to east.

The density and distribution of lupin at the western tip of the Spit (Area 1, Figure 4) has declined since 2005. Plants recorded in 2015 were typically small scattered juveniles and seedlings, but larger plants, including some flowering, were observed in the backdune where bracken may have frustrated control efforts. We observed large numbers of seedlings near dead lupin plants, indicating the presence of a seed bank. This seed bank appears to be restricted to within a few meters of living or recently dead lupin.

Little lupin was observed for the next 5km of coast to the boundary between the Western Conservation Area and the Pacific Ocean-Foreshore Conservation Area (Area 2, Figure 4). The one outlier that was recorded in 2005 was no longer present and we found no seedlings

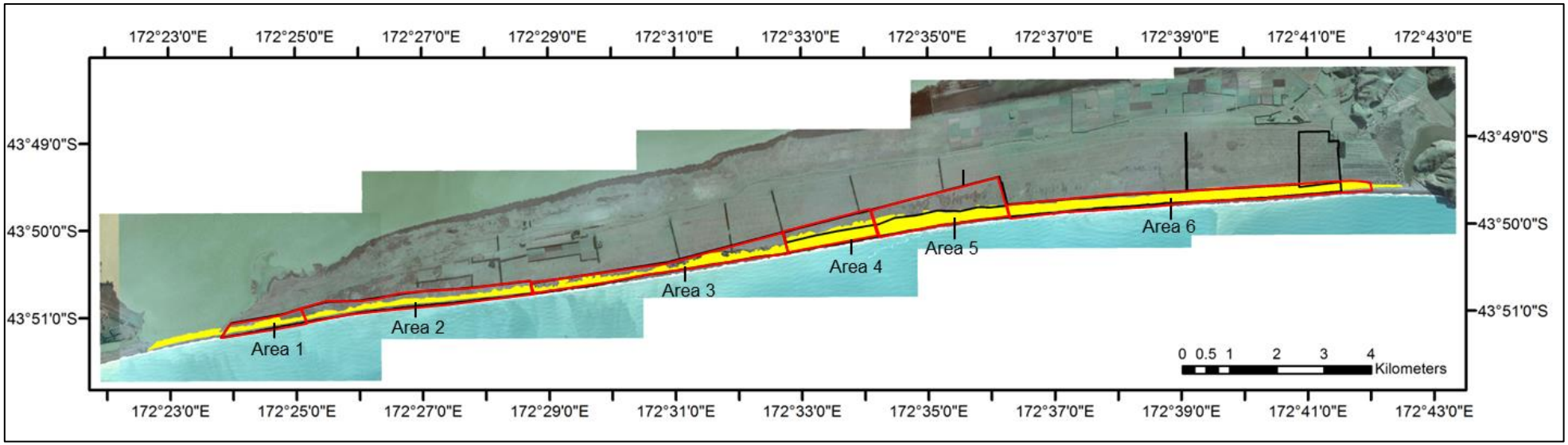

Figure 4. Boundaries of the areas used to describe the distribution and density of the surveyed weed species at Kaitorete Spit, October 2015.

here to indicate the presence of a related seedbank. The main infestation in 2005 extended approximately 800m west of the Pacific Ocean-Foreshore Conservation Area. We observed only one mature plant along this length of coast in 2015, and only a few seedlings suggesting that the seed bank is likely to be small. The western extent of the main lupin infestation now lies at the boundary between the Western Conservation Area and the Pacific Ocean-Foreshore Conservation Area

Most lupin was recorded over the next 5.5km of coast, within the Pacific Ocean-Foreshore Conservation Area (Area 3, Figure 4). The current programme of lupin control has not substantially altered the alongshore distribution of lupin here; however it has been successful in reducing the density of lupin. Lupin formed a dense cover of mature plants along this section of the coast in 2005. Lupin is still present in large numbers, but now forms a semi-continuous cover comprising numerous small patches of mature plants and scattered individuals (Figure 5). Most plants were found in the relatively stable dune areas inland of the foredune, with only scattered individuals in the foredune environment. The sand dunes along this section of coast are relatively mobile with frequent blowouts. Abundant seedlings were also recorded throughout the more stable dune environments inland of the foredune, indicating a well-established seed bank is present in this area. Most plants were of similar height and size suggesting that they have established from the seed bank following control. Most of the lupin observed was flowering.

We observed relatively little lupin within the Lone Pine block (Area 4, Figure 4). Several large patches of lupin were observed in the backdune, particularly where bracken was present. These plants were flowering and abundant seedlings were observed. Very few lupin plants were observed within the foredune and parabolic dune environments, and relatively few seedlings were present. These observations are consistent with studies of the lupin seed bank which found that the quantity of seed in this area has been greatly reduced after several years of control (Ghaemaghamy 2011).

The lupin surveyed in 2005 was present as a scatter of isolated plants and small patches between the Lone Pine block and the Rocket Pad (Area 5, Figure 4). We recorded numerous patches of dense lupin (>20m^2 in area) with abundant isolated plants between the Lone Pine block and the Rocket Pad in 2015 (Figure 6). Many of these plants were flowering, but it should be noted that our survey occurred the week before these plants were controlled and had not yet set seed. Seedlings covered large areas where lupin had recently been removed (as evident by dead and decaying plants). There is clearly an abundant seedbank in this area, but it appears to be restricted to within a few meters of living or recently dead lupin.

Overall, we observed more lupin through this area, between the Lone Pine block and the Rocket Pad, in 2015 than in 2005, although lupin remains relatively sparse through this section of the dunes. It is not clear whether this apparent increase in lupin density is due to differences in search intensity between the two surveys, or does in fact record an increase in lupin.

Figure 5. Image showing the semi-continuous lupin cover surveyed in 2015 that is representative of the main infestation located in the Pacific Ocean-Foreshore conservation. The dashed line marks the boundary between the relatively mobile foredune with sparse, scattered lupin, and the more stable inland dune environments where lupin was relatively dense. The inset shows a nearby section of the spit in 2005 and illustrates the decline in lupin density since 2005 (source M. Hilton, 2005).

Figure 6. Dense but patchy lupin present between the Lone Pine block and the Rocket Pad, October 2015. Note the yellow flowering lupin on the dunes in the background.

We observed a scatter of plants between the Rocket Pad and Birdlings Flat (Area 6, Figure 4). Overall we recorded fewer occurrences of lupin here in 2015 than in 2005 (10 compared to 17, respectively), particularly in the vicinity of Birdlings Flat. Most lupin recorded in 2015 occurred as one or two isolated plants, but two larger occurrences comprising multiple plants (12-19 plants within areas measuring approximately 10x5m) were also recorded. Forty percent of the lupin recorded in 2015 was located close to plants present in 2005, indicating that they established from the seed bank after the parent plants were controlled. Of the remaining 60%, a portion may have been present in 2005 but missed by the surveyors (i.e., the 2005 search tracks pass some distance (>20m) from many plants recorded in 2015), or alternatively have originated from seed dispersed from mature populations since 2005. Plants were typically small (<1m high) and many were flowering.

Marram grass

Marram grass forms a dense cover at the western tip of Kaitorete Spit, between the crib and the Lake Ellesmere outlet. A scatter of isolated plants and small colonies also occur the length of Kaitorete Spit, with conspicuous concentrations within the Pacific Ocean-Foreshore Conservation Area adjacent to the Bayley's farmhouse, at the Rocket Pad, and at a site 1km west of Birdlings Flat.

Most of the marram observed was recorded close to the beach. These plants almost certainly established from sea-dispersed rhizomes. Some sites contained isolated plants. These were typically small in size, indicating they established within the last couple of years (as shown in the cover photo). Most of the marram recorded close to the beach, however, comprised colonies of multiple tussocks over areas between 10 and 400m^2 (Figure 7). These plants are, therefore, multiple years in age. We also recorded large colonies of marram further inland at several sites. Some of these plants have established from deliberate plantings (adjacent to the Bayley's farmhouse and at the Rocket Pad, for example), or from secondary seed dispersal. Most of the larger colonies of marram, along both the beach and further inland, showed signs of having been sprayed in the past (e.g. dead leaf material). However, all had recovered when we observed them in 2015, with no obvious signs of stress. Several plants were flowering and we also observed the growth of new horizontal rhizomes at a number of sites indicating vegetative spread.

Marram has had, to date, little effect on the morphology or dynamics of the Kaitorete dunes. Dunes have been stabilised where marram is present, but marram does not yet appear to be trapping large amounts of sand and forming dunes. The large size of the sand grains at Kaitorete Spit, combined with the widespread stabilisation of the dunes by lupin, has historically restricted aeolian sand transport over much of the Spit. The geomorphic effect of marram could be expected to increase as the mobility of the dunes increases following lupin control, and as marram expands its range.

Figure 7. A typical marram colony observed at Kaitorete Spit, October 2015.

Overall we recorded more populations of marram in 2015 then were recorded in 2005. Most colonies of marram west of the Rocket Pad are long established and have been revealed following the control of lupin. The differences in search intensity between the 2005 and 2015 surveys may account for a portion of new plants recorded east of the Rocket Pad; however, the 2005 survey team would probably have observed these plants were they present at that time (i.e., the 2005 search tracks pass close to or over the location of plants observed in 2015). The majority of these new plants occurred close to or on the beach, suggesting initial establishment from sea-dispersed rhizomes and the subsequent vegetative spread from the growth of rhizomes.

Iceplant

The distribution of iceplant in 2015 is similar to the 2005 data. Plants are concentrated at the western end of the Spit near the crib and at the eastern end of the Spit near Birdlings Flat. All of the plants recorded within the survey area occurred as small colonies (<10m^2), but more extensive colonies were present outside the survey area, both at the western end of the Spit between the crib and the Lake Ellesmere outlet and in front of the Birdlings Flat village.

The number of iceplant colonies has decreased from 27 in 2005 to only nine colonies in 2015, probably due to the DOC control. We observed only one new outlying colony within the survey area, located approximately 2km west of Birdlings Flat (172°40’16’’E, 43°49’39’’S). Examination of the 2005 survey tracks indicates that this colony has established since 2005.

Gorse

The distribution of gorse has decreased in extent since 2005. Hilton *et al.* (2006a) recorded scattered plants the length of the Spit. In 2015 gorse was largely present at the western end of the Spit within the Western Conservation Area. This gorse typically occured as small patches comprised of multiple plants (16-1600m^2 in area) in close proximity to recently dead gorse. It has likely established from the seedbank following control of the parent plant. Many of these plants were flowering.

Only two plants of gorse was recorded along the next 7km of coast, within the Pacific Ocean-Foreshore Conservation Area and Lone Pine block (Areas 3 and 4, Figure 4). These plants have probably established since 2005 due to long-distance seed dispersal. Several infestations of gorse were recorded between the Lone Pine block and the Rocket Pad (Area 5, Figure 4). Gorse inland of the active dunes occurred here as small patches comprised of multiple plants, with a few single isolated plants on the active dunes. Three occurrences of gorse were recorded between the Rocket Pad and Birdlings Flat (Area 6, Figure 4) – one small cluster of 10 plants (indicating the presence of a seed bank here) and two single

isolated plants (indicating long distance dispersal of seed). Several of these plants were also flowering.

Boxthorn

The distribution of boxthorn at Kaitorete Spit has declined in extent since 2005. Hilton *et al.* (2006a) recorded scattered plants the length of the Spit, but boxthorn was less common towards Birdlings Flat. In 2015 boxthorn was restricted to the western portion of the Spit, with no plants observed east of the Lone Pine block (Areas 5 and 6, Figure 4). Boxthorn was also absent from a 1km length of coast at the western end of the Spit, probably as the result of control works conducted here in 2015. Many plants were located in the foredune with a scatter of plants further inland. Plants were typically present as mature shrubs 1-3m high.

A similar number of plants were observed in 2005 and 2015, despite the decline in the extent of boxthorn since 2005 — 163 plants in 2015 compared to 164 plants in 2005. The majority of plants recorded in 2015 were new occurrences, explaining the similarity in the number of boxthorn plants recorded between 2005 and 2015. While the difference in search intensity between the surveys may account for a portion of these new plants, the search tracks indicate that most are likely to have been observed by the surveyors if they were present in 2005 (the 2005 search tracks pass close to or over the location of plants observed in 2015). Boxthorn in 2015 was present as both clusters of multiple plants and scattered isolated plants. The former is suggestive of short distance seed dispersal over multiple generations and the presence of a seed bank. The latter indicates long-distance dispersal and range expansion.

Pine

The distribution of pine remains similar to that recorded in 2005. Most plants are found in the backdune of the Pacific Ocean-Foreshore Conservation Area. Most of the pines observed were saplings (up to 3m in height), in contrast to the many large trees recorded in 2005 by Hilton *et al.* (2006a). A few larger trees, which had survived control, were also present in 2015. Few of these trees have recently produced cones. We also observed several small pine trees in the backdune towards the western end of the Spit. These may have been present in 2005 and have likely established from the adjacent shelter belt. We found two outlying plants in the dunes at the eastern end of the Spit near Birdlings Flat at 172°41’12’’E, 43°49’35’’S. These plants were less than 1m in height, which suggests they have established recently (Figure 7).

Figure 7. An outlying pine seedling near Birdlings Flat, October 2015

Horned poppy

Plants are concentrated at eastern end of the Spit near Birdlings Flat and at the western end of the Spit adjacent to the to the Bayley's farm. A smaller concentration of plants on the shoreline of Lake Ellesmere at the western end of the Spit and one single isolated plant at 172°25'41''E, 43°50'58''S was recorded. Most sites contain single plants or small populations comprised of a few scattered individuals; but one larger population was recorded near Birdlings Flat where horned poppy had formed a semi-continuous cover within the wrack along a 600m section of the upper beach. Plant density here decreases from east to west indicating the source of this species is Birdlings Flat. Most horned poppy was recorded close to the beach, and has probably established from sea-dispersed seed. A few plants, however, were also found further inland indicating secondary seed dispersal and invasion. Plants were flowering when surveyed.

Californian poppy

One population of Californian poppy was recorded at the western end of the Spit on the shoreline of Lake Ellesmere. At this site scattered plants covered an area measuring approximately 1,110 m^2. Plants were flowering when surveyed.

Purple groundsel

Plants are concentrated at the eastern end of the Spit near Birdlings Flat, with a second smaller population approximately 1km west of the Lone Pine block within the Pacific Ocean-Foreshore Conservation Area. Most plants were recorded close to or on the edge of the beach suggesting establishment from sea-dispersed seed. Populations typically comprised multiple plants.

Broom

Broom is absent from most of the Spit except for a 2km length of the coast between the Lone Pine block and the Rocket Pad, and a single outlier at the gravel pits near Birdlings Flat. Most of the plants recorded between the Lone Pine block and the Rocket Pad occurred with bracken in the backdune area. Plants here were large and most were flowering. A scatter of plants was found within the active dunes adjacent to the Rocket Pad. These were small (<30cm high), but they were also flowering.

5.0 Discussion and management recommendations

The ecological restoration of Kaitorete Spit is a complex process and a full discussion of the issues is beyond the scope of the current report. The following comments may help the Department prioritise management actions while a full restoration strategy is developed.

Lupin

The current programme of lupin control has successfully reduced the density of lupin in the dunes of Kaitorete Spit, but lupin is still widespread due to the presence of a large and persistent seed bank. It has proved very difficult to eradicate lupin once it flowers and produces seed (Hilton and Konlechner 2008, 2009, Konlechner and Hilton 2010). The longevity of lupin seed at Kaitorete Spit is not yet known, but the presence of seedlings within the Lone Pine block, 10 years after any substantial production of seed, indicates that it will take over a decade of sustained management to control lupin to zero density at Kaitorete Spit.

We recommend that the current programme of lupin control is maintained, but that increased emphasis is placed on containing existing patches of lupin and preventing the further spread of this species. The time and cost required to successfully control lupin increases exponentially with time since invasion. Further, recent research has found that not all the impacts associated with lupin invasion at Kaitorete Spit are reversed when lupin is removed — the vegetation cover remains high due to the secondary invasion of non-native grasses and pasture plants (Konlechner *et al.* 2015). There is also some evidence that

the native plant communities may not fully recover following lupin removal, particularly those associated with the deflation surface environments. Weed control is not sufficient by itself to restore the conservation values of the Kaitorete dunes once lupin has established. The most effective way to protect the conservation, landscape and geomorphic values associated with the active dunes of Kaitorete Spit is, therefore, to prevent new populations of lupin from establishing.

Preventing the further spread of lupin is particularly critical at the eastern end of the main infestation between the Lone Pine block and the Rocket Pad. Currently the lupin here is widespread and appears to have increased in density since 2005. This portion of the dunes retains most of the intact deflation surface habitats present on the Spit, and a disproportionate number of significant dune species are found here, including the endemic *Craspedia* "kaitorete". The conservation of habitat for these species depends on preventing lupin from establishing within these deflation surfaces.

Marram

The current approach to marram control does not appear to be successfully reducing the extent of marram at Kaitorete Spit. This is probably because the application of herbicide since 2010 has been intermittent, which has allowed marram to re-establish from its bud-bank between treatments. We found evidence that marram is continuing to expand its range along Kaitorete Spit, through both the establishment of new populations from sea-dispersed rhizome and the vegetative spread of rhizomes from existing populations.

It would be timely to consider eradicating marram from the dunes between the crib and Birdlings Flat. The density of marram here is currently low and marram is yet to have any significant geomorphic or ecological impact. Moreover, it is unlikely to have formed a significant seedbank. Our experience in controlling marram on Stewart Island is that the cost and time required to eradicate marram increases exponentially with the size of the population and density of the seedbank. There is, therefore, an opportunity to control all existing populations of marram at the Spit relatively efficiently.

Controlling marram to zero-density will require the annual application of herbicide to prevent regeneration from rhizomes. The limited rhizome system associated with marram at Kaitorete combined with a small seed bank means eradication might be achieved with a 3-5 year programme. Marram will continue to invade from populations further up the coast from sea-dispersed rhizomes, but these should be easy to locate and remove before they flower, provided the current system of annual grid-searching is expanded and maintained.

Iceplant

The current programme of iceplant control appears to be effective and should be maintained. There is the opportunity to control iceplant to zero-density between Birdlings

Flat and the crib given the low density of iceplant here and the relatively short lived seed bank of this species.

The presence of a new colony 2km west of Birdlings Flat is of concern. It demonstrates that iceplant is able to disperse and establish over long distances in the dunes at Kaitorete. This plant may have established from seed dispersed by animals (lagamorphs, for example), or from vegetative fragments transported by people (by vehicles, for example), but it probably originated from the large colony of iceplant in front of the Birdlings Flat village. The large colonies of iceplant west of the crib at the western end of the Spit similarly serve as a potential source of propagules. Ongoing surveillance will remain critical to limit the spread of iceplant while the colonies at Birdlings Flat and the crib remain.

Gorse

The current programme of gorse control has successfully reduced the density of gorse at Kaitorete Spit, but large amounts of gorse remain, largely due to the ability of this species to form a long-live seed bank. Much of the gorse we recorded comprised young plants which have regenerated from the seed bank following control of the parent plants. We also observed several new plants which have established some distance from existing infestations, which shows that gorse is dispersing in the dunes at Kaitorete Spit.

We recommend that the current program of gorse control be maintained with the emphasis placed on containing existing patches of gorse and preventing any further spread of this species, since it is difficult to eradicate gorse once it flowers and produces seed. All gorse east of the Bayley's farm should be controlled as soon as possible to limit development of the seed bank. Ongoing surveillance will remain critical so long as gorse remains on the Spit.

Boxthorn

The distribution of boxthorn has declined in extent since 2005 and is now absent from the eastern half of the Spit. Boxthorn, however, is continuing to spread in the western half of the Spit.

We recommend that Boxthorn should be controlled to zero density east of the Western Conservation Area. In this area boxthorn is currently present at low densities – it occurs primarily as single plants scattered along the foredune. Within the Western Conservation Area short term management should focus on preventing the establishment of new plants, but with the eventual goal of controlling boxthorn to zero density along the length of the Spit. Ongoing surveillance will remain critical while flowering populations of boxthorn remain on the Spit. Finally, we recommend that the longevity of boxthorn seed at Kaitorete be investigated given the uncertainty around the persistence of the seedbank.

Pine

The current program of pine control has successfully reduced the density of pine in the dunes at Kaitorete, but large numbers of pine trees remain, largely because of re-establishment from the seed bank. Most of the pine surveyed in 2015 was found close to the (now dead) trees recorded in 2005 by Hilton *et al.* (2006a), which suggests there has been limited seed dispersal from the original trees. The outlying plants at the eastern end of the Spit near Birdlings Flat, however, are of concern as this demonstrates that pine is able to disperse and establish over long distances in the dunes at Kaitorete. These plants probably established from seed dispersed from the nearby shelter belts.

The other weed species surveyed present a more immediate threat to Kaitorete Spit. However, we recommend that the current programme of pine control is maintained given the substantial investment in this programme that has occurred to date and the good progress made towards eradicating pine. We recommend that the existing populations continue to be controlled at regular intervals to remove seedlings before they reach maturity and produce seed. Finally, surveillance for new populations should be ongoing because of the large number of shelter belts present on the Spit.

Horned poppy

This study provides the first data on the distribution of horned poppy at Kaitorete Spit. Currently horned poppy is present at Kaitorete Spit in low densities, and there is an opportunity to control horned poppy to zero density. Most plants were located close to the beach and should be easy to locate and remove. These plants have probably established from sea-dispersed seed originating from the relatively large population at Birdlings Flat. Of concern, however, were the few plants found further inland – these plants suggest ongoing secondary dispersal and invasion. Horned poppy will become increasing difficult to control as it continues to establish inland.

We recommend that regular control of this species be reinstated. Control should target all known populations before seed set, including the large population at Birdlings Flat. Invasion via sea-dispersed seed will remain ongoing while this population remains. Finally, it is not known whether horned poppy at Kaitorete is an annual or perennial species. We recommend that the reproductive biology of horned poppy at Kaitorete be investigated given the potential of this species to produce seed in its first year of growth.

Californian poppy

We did not observe Californian poppy within the active dunes at Kaitorete Spit. One small population of this species was surveyed on the shore of Lake Ellesmere at the western end of the Spit. This occurrence suggests seed dispersal in water; however, there is little information on the ability of this species to disperse in water. This population does not at

present directly threaten the conservation values of the Spit, but there is the potential for it to spread. DOC may therefore wish to consider controlling Californian poppy at this site.

Purple groundsel

Purple groundsel is present at Kaitorete Spit in relatively low densities, and there is an opportunity to control this species to zero density. The current programme of control should be maintained. Ongoing surveillance for new populations will remain critical while flowering populations and a seed bank remain on the Spit.

Broom

We observed little broom in the active dunes at Kaitorete, with only a few scattered plants at the Rocket Pad and a single outlier at the gravel pits near Birdlings Flat. These plants should be controlled at soon as possible to prevent the further invasion of broom at Kaitorete. Most of the broom was observed within bracken inland of the active dunes between the Lone Pine block and the Rocket Pad. This population currently poses a relatively minor threat to the values of the Spit, but could potentially serve as a source of seed if left uncontrolled.

Other observations

Garden waste dumps were observed at two locations at the eastern end of the Spit — at the gravel pits and a second dump 3.5km west of Birdlings at 172°39’23’’E, 43°49’40’’S. This dump consisted of a single mound of vegetation, and has introduced new potential weed species to the Kaitorete dunes including a mallow sp., alyssum (*Lobulaia maritima*), milkweed (*Euphorbia peplus*) and bedstraw (*Galium aparine*) (Figure 8). This was the only site where these species were observed. They should be controlled as soon as possible to limit their spread.

We observed lagamorph (rabbit and hare) sign throughout the dunes. These species pose a direct threat to the conservation values of the Spit. They can disperse the seed of weed species present at the Spit, namely iceplant. Further, they browse on native dune species, particularly juvenile pīngao. Since 2005, when we first started working at Kaitorete, we have never observed a pīngao seedling. We strongly suspect that browse by lagamorphs are a significant contributing factor. We recommend that the impact of lagamorph browse on pīngao recruitment at Kaitorete be investigated given the rarity and significance of this species nationally. This study would benefit dune conservation elsewhere in New Zealand as currently the impact of lagamorphs on dune vegetation is poorly understood. Some consideration could be given to lagamorph control; however we recognise that to do so effectively would be difficult and expensive. Preventing the spread of weeds at the Spit will probably provide better conservation outcomes, at least in the short term.

Figure 8. Garden waste dump found at 172°39’23’’E, 43°49’40’’S.

We observed nationally significant dune plants through the dunes on the Spit. Some species, pīngao for example, are widespread and occupy multiple dune environments (foredune, depositional lobes, deflation surface) from Birdlings Flat to the crib. Others, such as *Craspedia* “kaitorete”, and *Carmichaelia appressa,* are restricted to only a few sites. *Craspedia* for, example, is found almost solely in the deflation environments between the Rocket Pad and the Lone Pine block. Species with restricted ranges are vulnerable. We recommend that existing information on the distribution of native dune species at Kaitorete is compiled and botanical surveys conducted where necessary. This study will allow identification of important and vulnerable parts of the Spit, and provide information that will assist the Department to prioritise control. It may also assist in raising the national profile of the Kaitorete dunes.

Finally, we noted that dune stability increases from west to east. There was almost no evidence of any aeolian dune mobility at the eastern end of the Spit. In contrast, the western end of the Spit is characterised by large areas of bare or sparsely vegetated sand. Mobile dunes, comprising sandsheets, blowouts and slip faces, are present well inland. The stability of the eastern end of the Spit is largely natural, but we felt it important to note here for two reasons. First, the vigour of pīngao is dependent on frequent burial by sand. Much of the pinago in the eastern section of the Spit is moribund and/or dead (Figure 9). Secondly, the stability of the eastern dunes has allowed non-native grasses and other pasture weeds to colonise much of the dune surface. Any increase in dune mobility will reverse these impacts, but the long-term management of this part of the Spit should recognise the natural dune dynamic here. Consideration could be given to establishing a

seed source of secondary and late succession dune species more representative of stable dunes, for example.

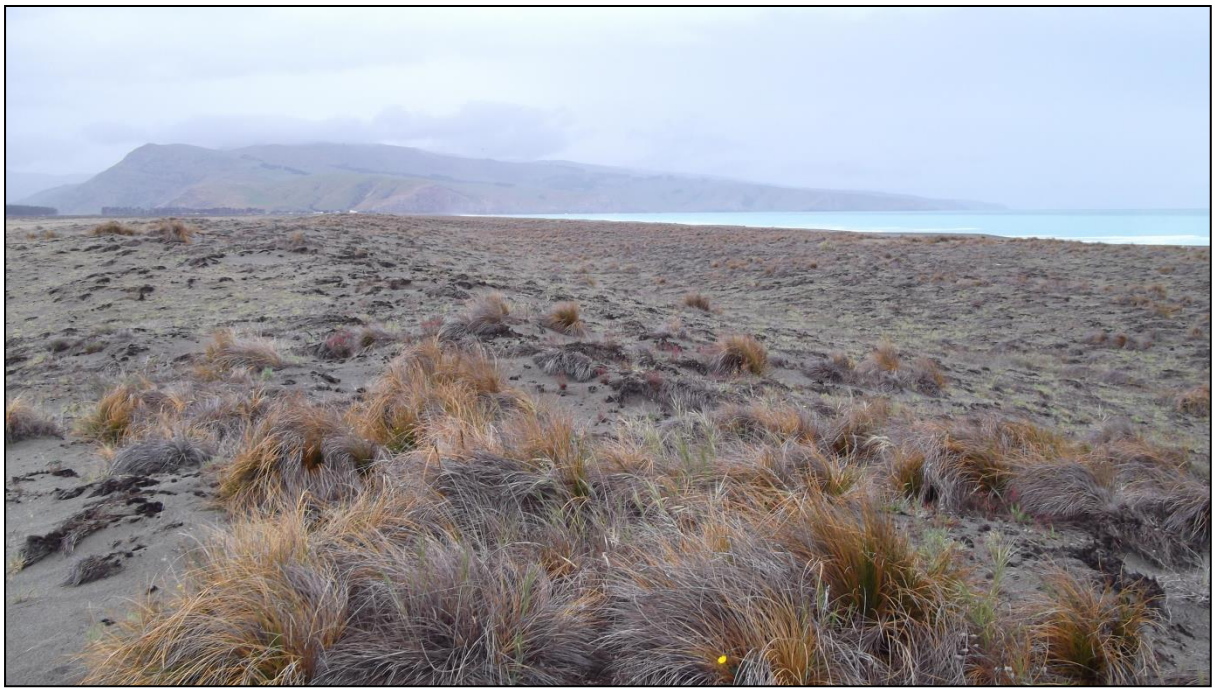

Figure 9. The stable dunes at the eastern end of the Spit. Note the large proportion of dead and moribund pīngao.

6.0 Conclusions

The Kaitorete Spit sand dunes contain exceptional landscape, botanical, ecological and geomorphic values. These values are threatened by the ongoing invasion and spread of weed species. Over the past decade, since 2006, control programmes implemented and facilitated by DOC have been successful in reducing the density and distribution of most of the weed species examined in the present study. Significant populations of all species examined still remain, however, because of persistent and long-lived seed banks and non-controlled populations which serve as a source of propagules. Intermittent control, doubtless related to limited operational funding, has also contributed.

All of the weed species examined in the current study remain a priority for control, but future control programmes can be designed to target multiple species because of the overall sparseness of the weed species along most of the Spit. This strategy has already been employed with great success between the Birdlings Flat village and the Rocket Pad through an annual grid search focussed on multiple species. We recommend that DOC continue to support and facilitate this annual search, but that it is expanded to target all the weed species covered in this report. Isolated plants and small populations of the target

species west of the Rocket Pad could similarly be controlled through a series of grid searches. Implementing a programme of systematic grid-searches which covers the entire Spit on a regular basis would both satisfy the need that this study has identified for ongoing surveillance for new populations of all the weed species, but would also contain and prevent the spread of larger existing populations.

The formation of seedbanks poses the biggest hurdle to the successful eradication of most weed species at Kaitorete. Controlling new populations and outlying individuals before seed set is critical in limiting the effect of weeds on the values of the Spit. Many species do not set seed until at least their second year of growth (e.g. lupin, pine, marram). Control of these species could occur biennially provided managers are confident all flowering plants are identified and removed during each grid search. Other species (e.g. purple groundsel, horned poppy) will have to be controlled annually.

Finally, we recommend that regular and systematic monitoring be implemented to measure the effectiveness of the operations in removing target weed species, as well as the recovery of desired ecological and geomorphic properties. Management plans that clearly identify restoration goals and the proposed sequence of actions required to achieve these should be produced for the Spit.

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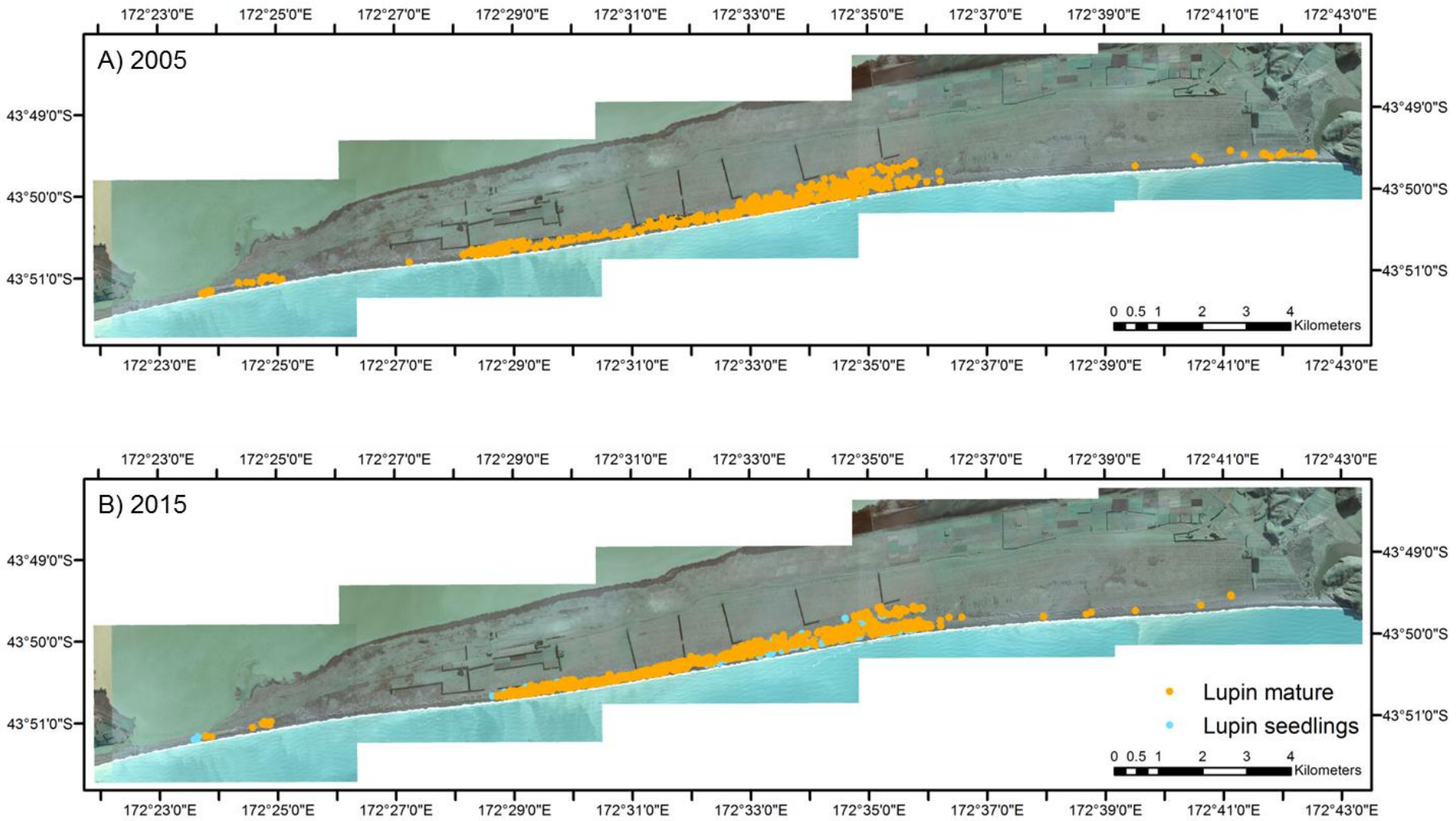
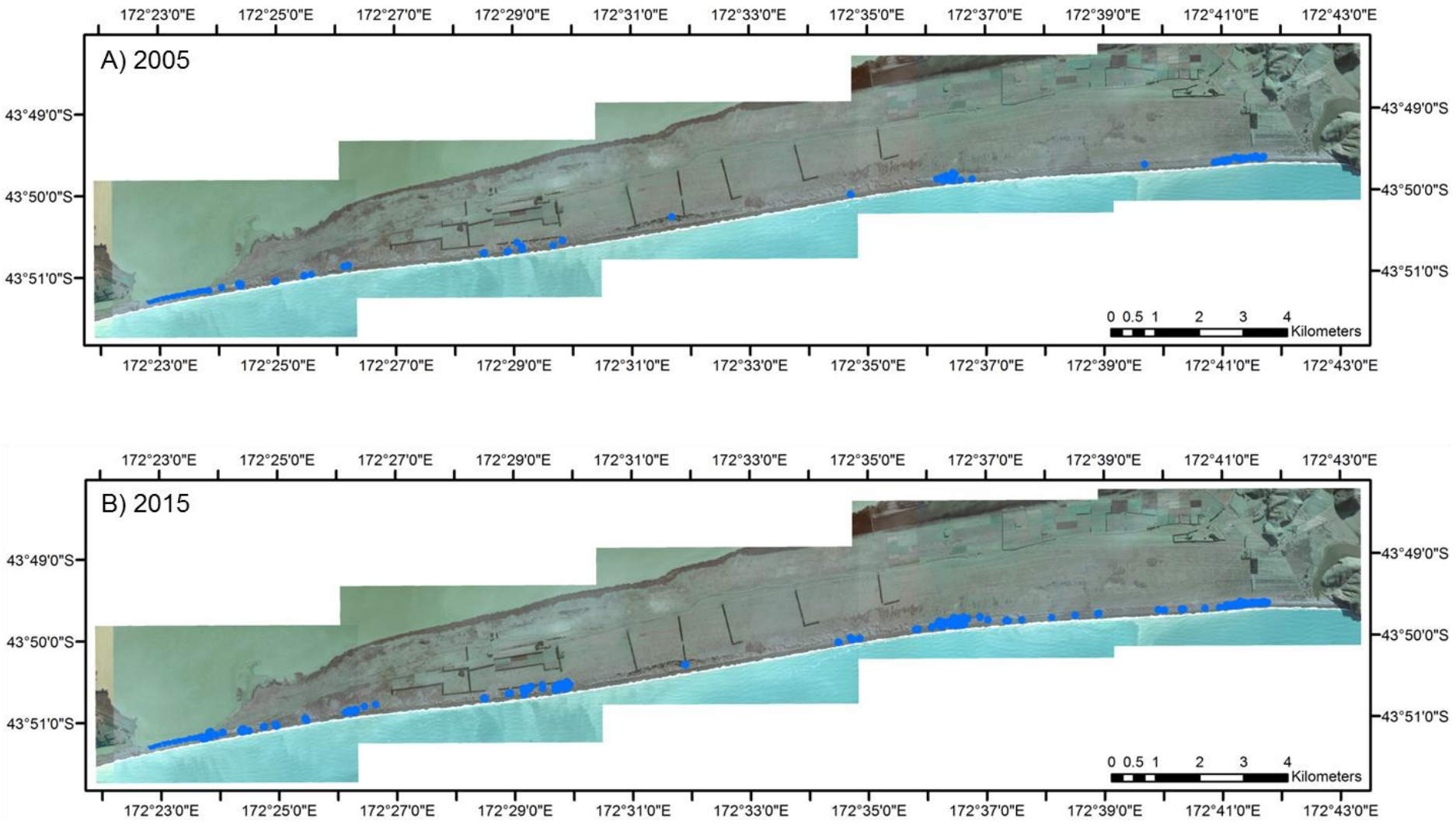
Appendix A

Distribution of the target weed species at Kaitorete Spit in 2005 and 2015.

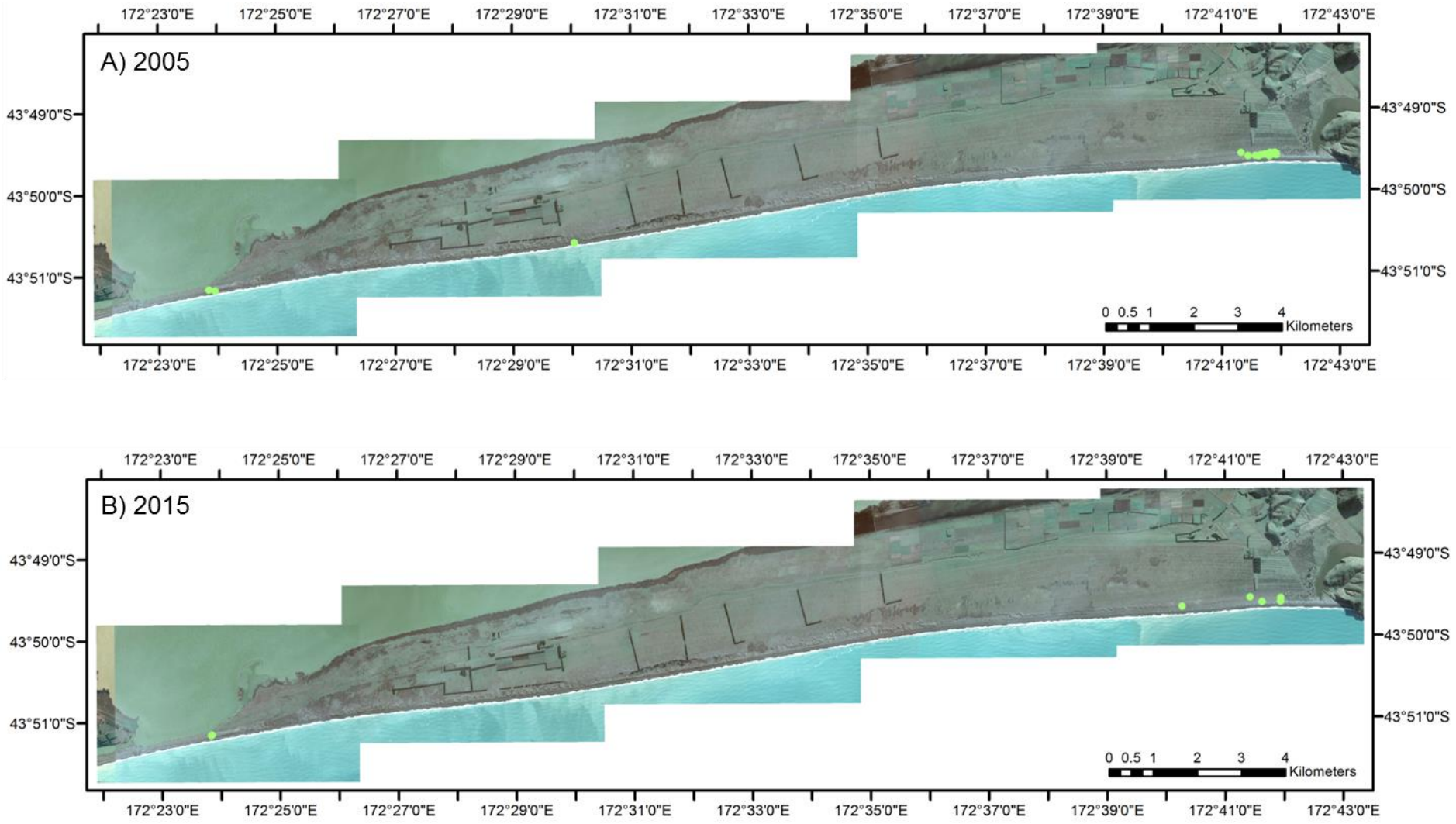
Distribution of lupin at Kaitorete Spit in 2005 and 2015



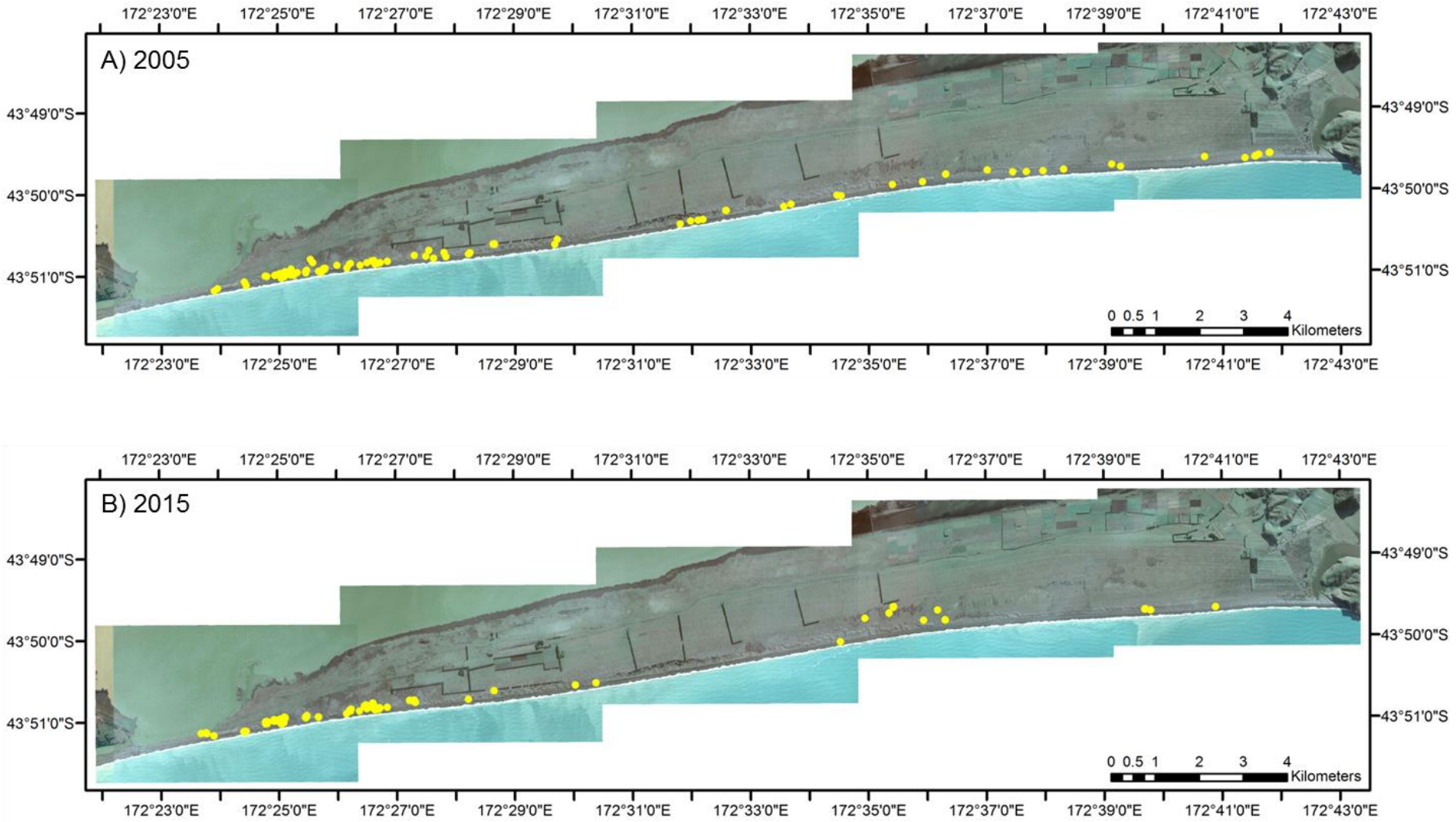
Distribution of marram grass at Kaitorete Spit in 2005 and 2015



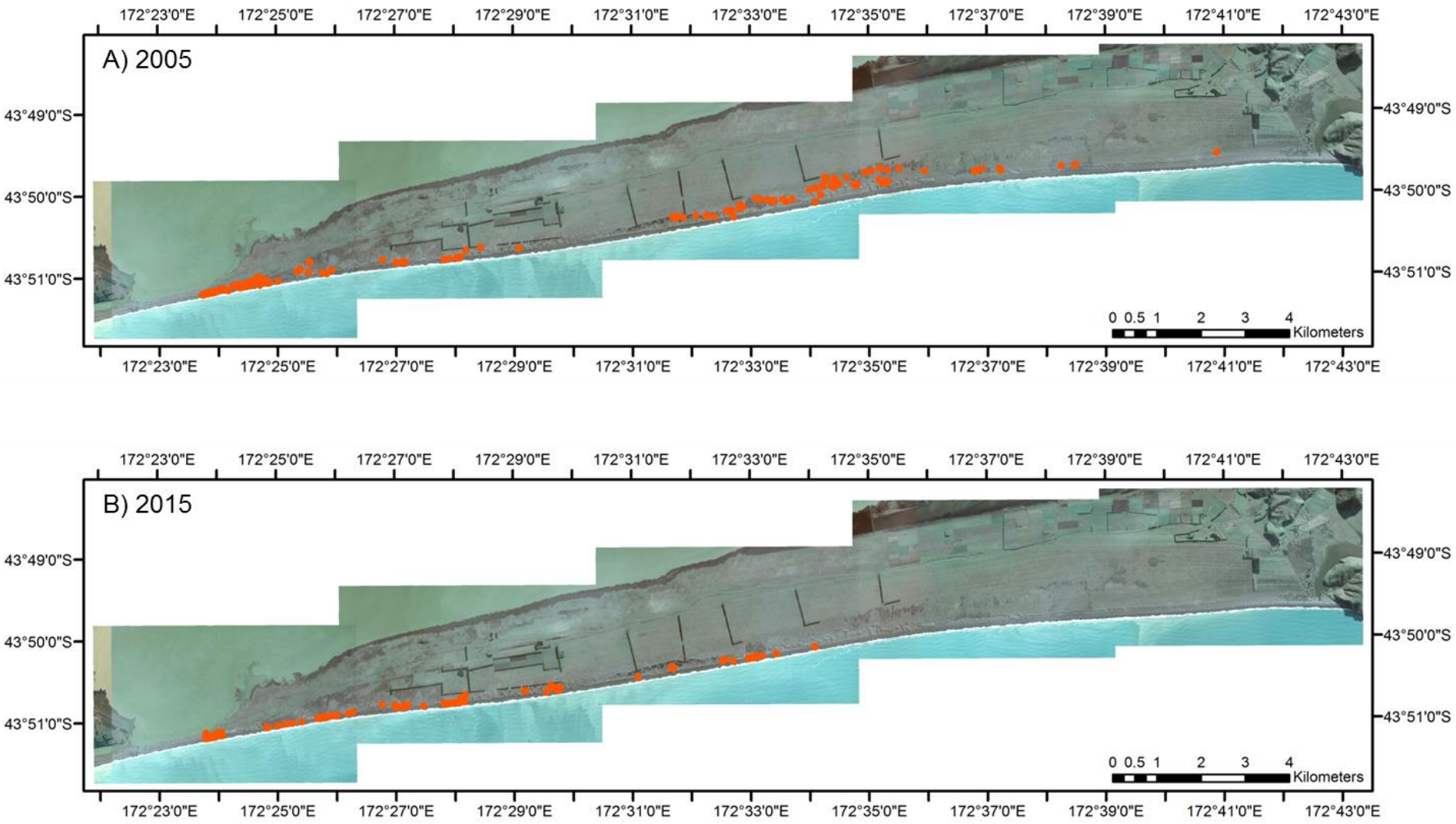
Distribution of iceplant at Kaitorete Spit in 2005 and 2015



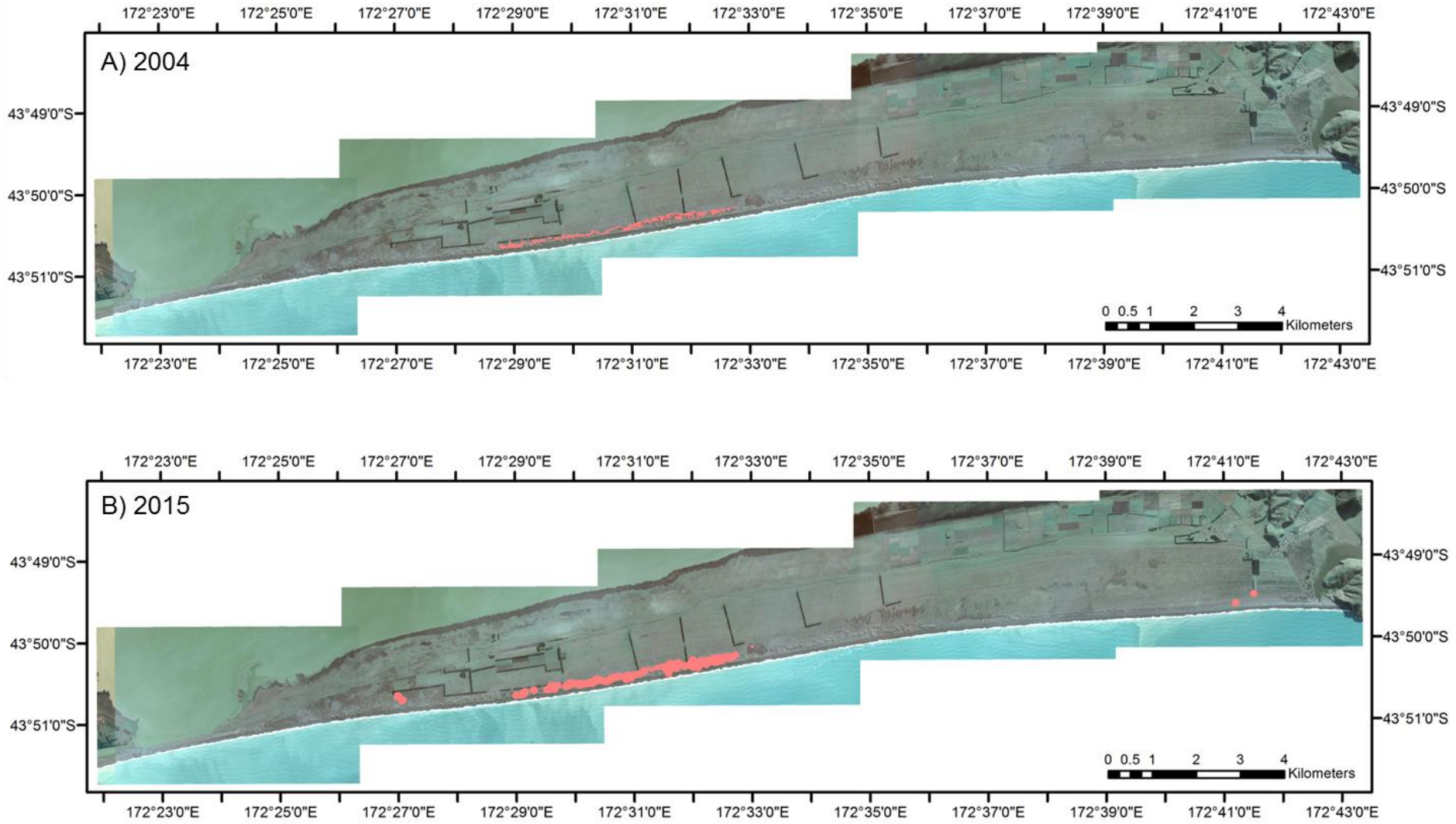
Distribution of gorse at Kaitorete Spit in 2005 and 2015



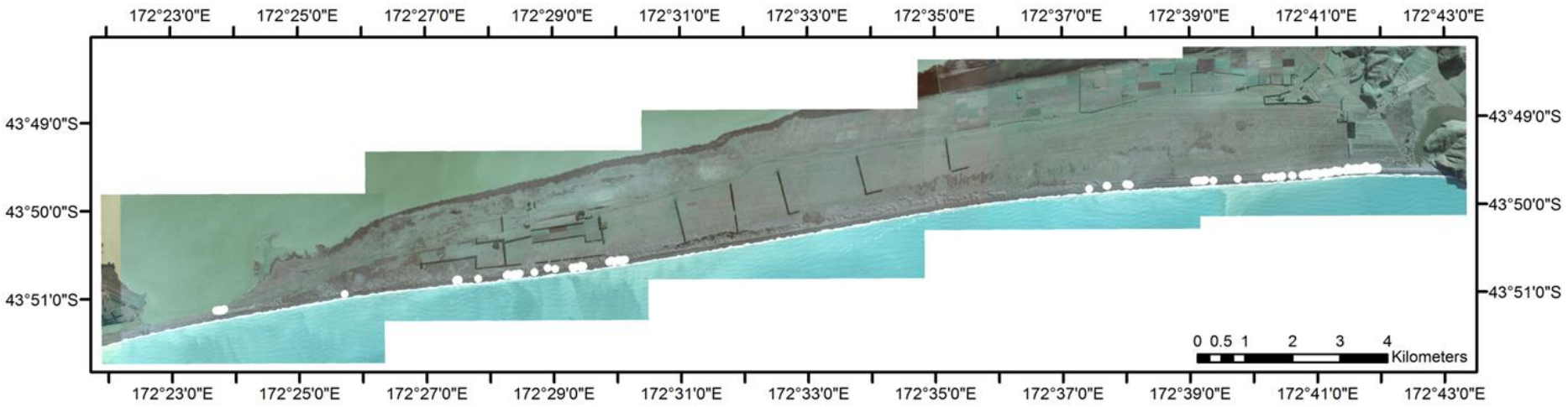
Distribution of boxthorn at Kaitorete Spit in 2005 and 2015



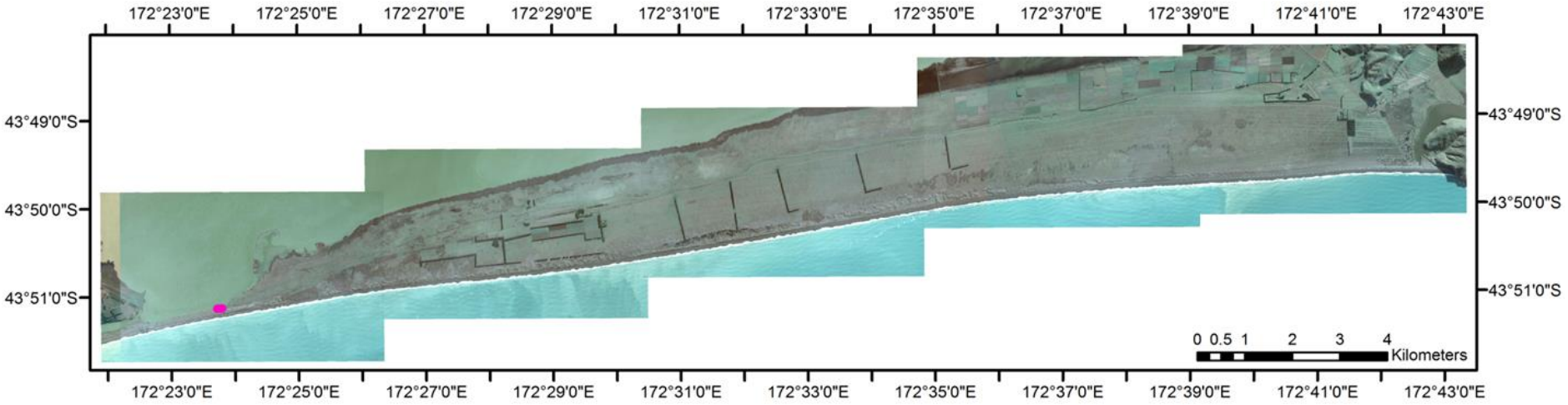
Distribution of pine at Kaitorete Spit in 2004 and 2015



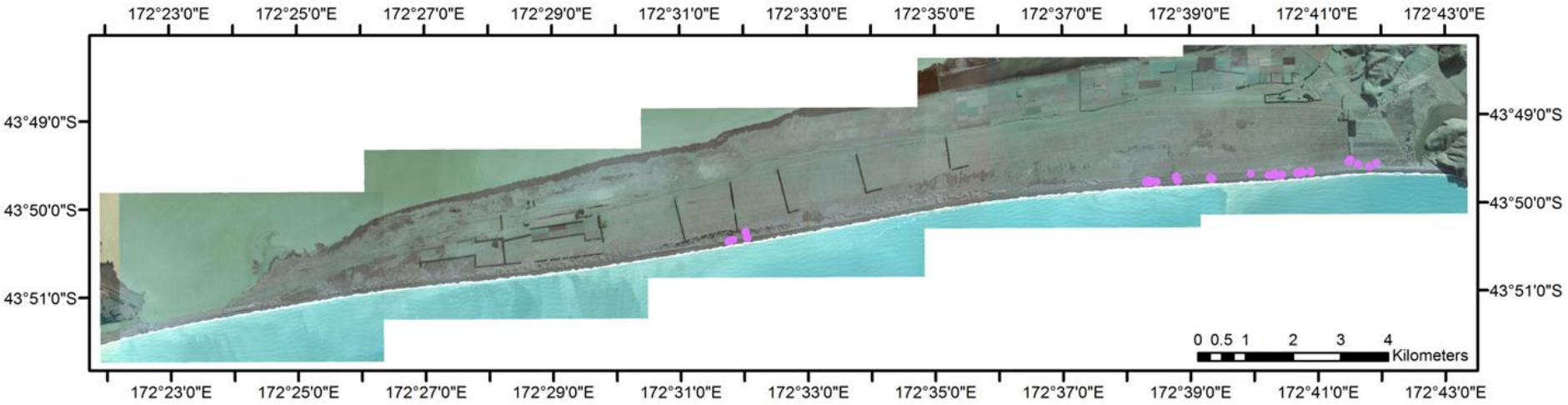
Distribution of horned poppy at Kaitorete Spit in 2015



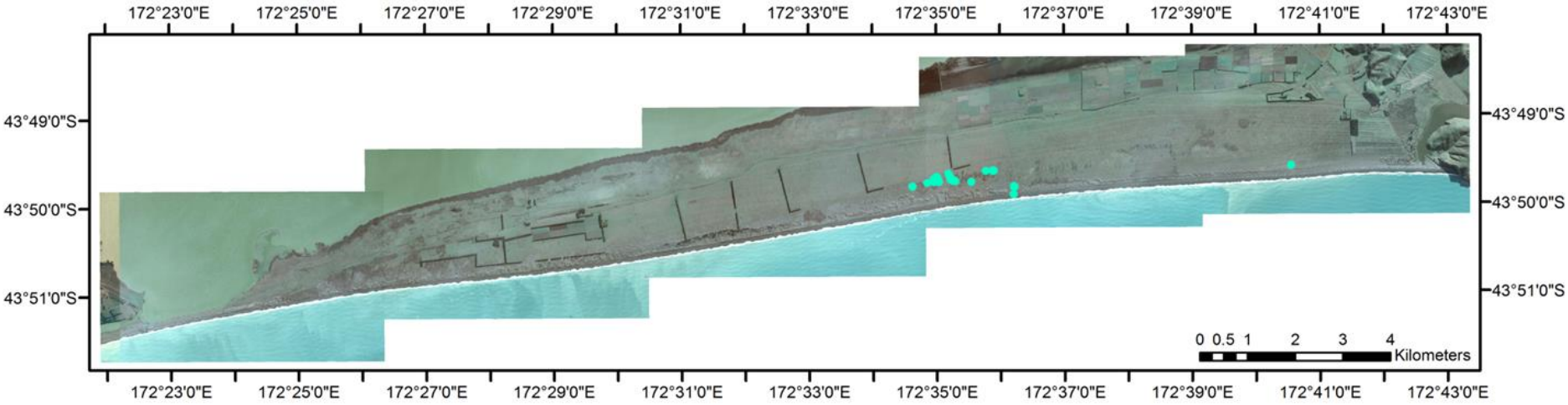
Distribution of Californian poppy at Kaitorete Spit in 2015



Distribution of purple groundsel at Kaitorete Spit in 2015

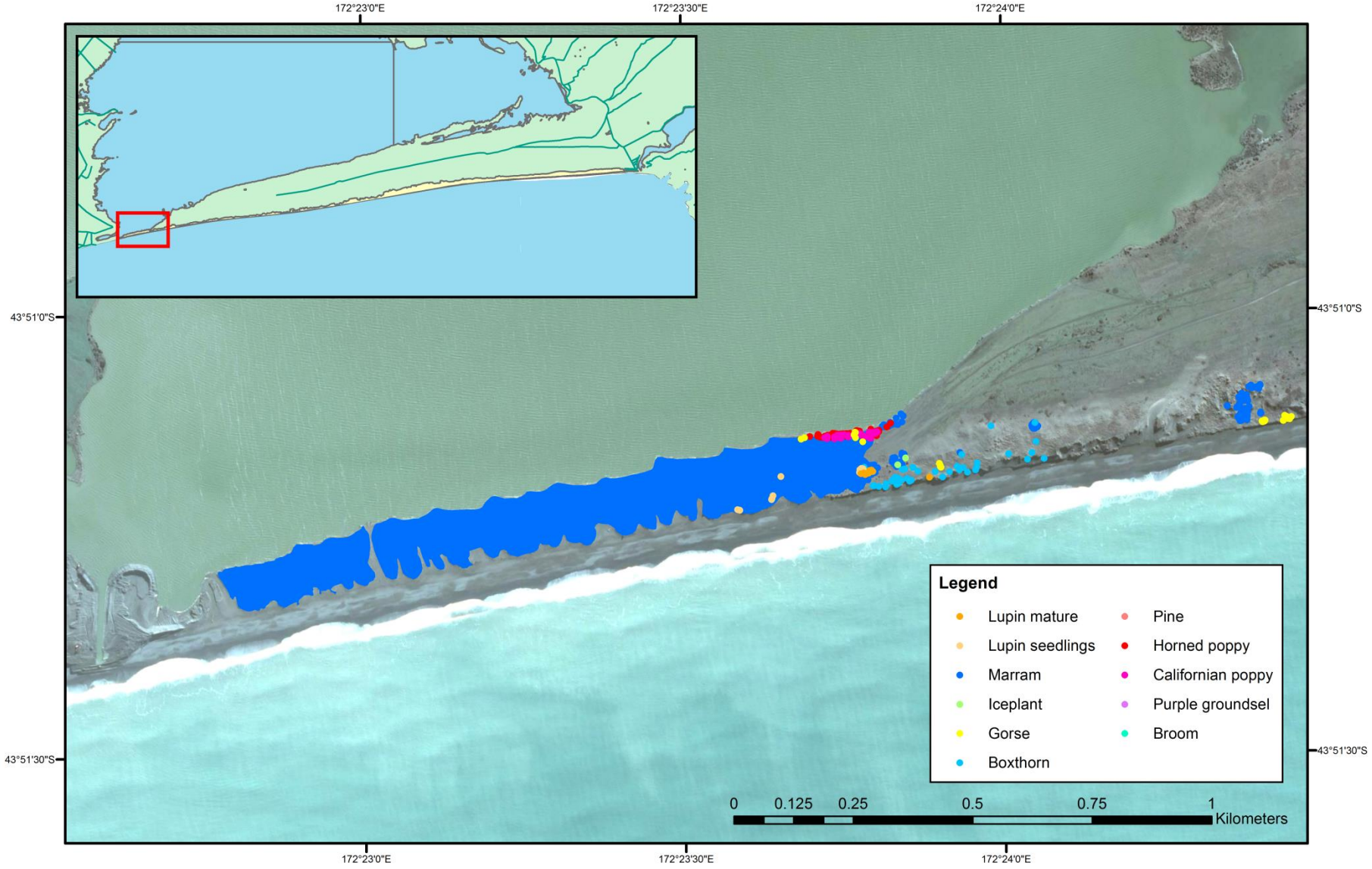


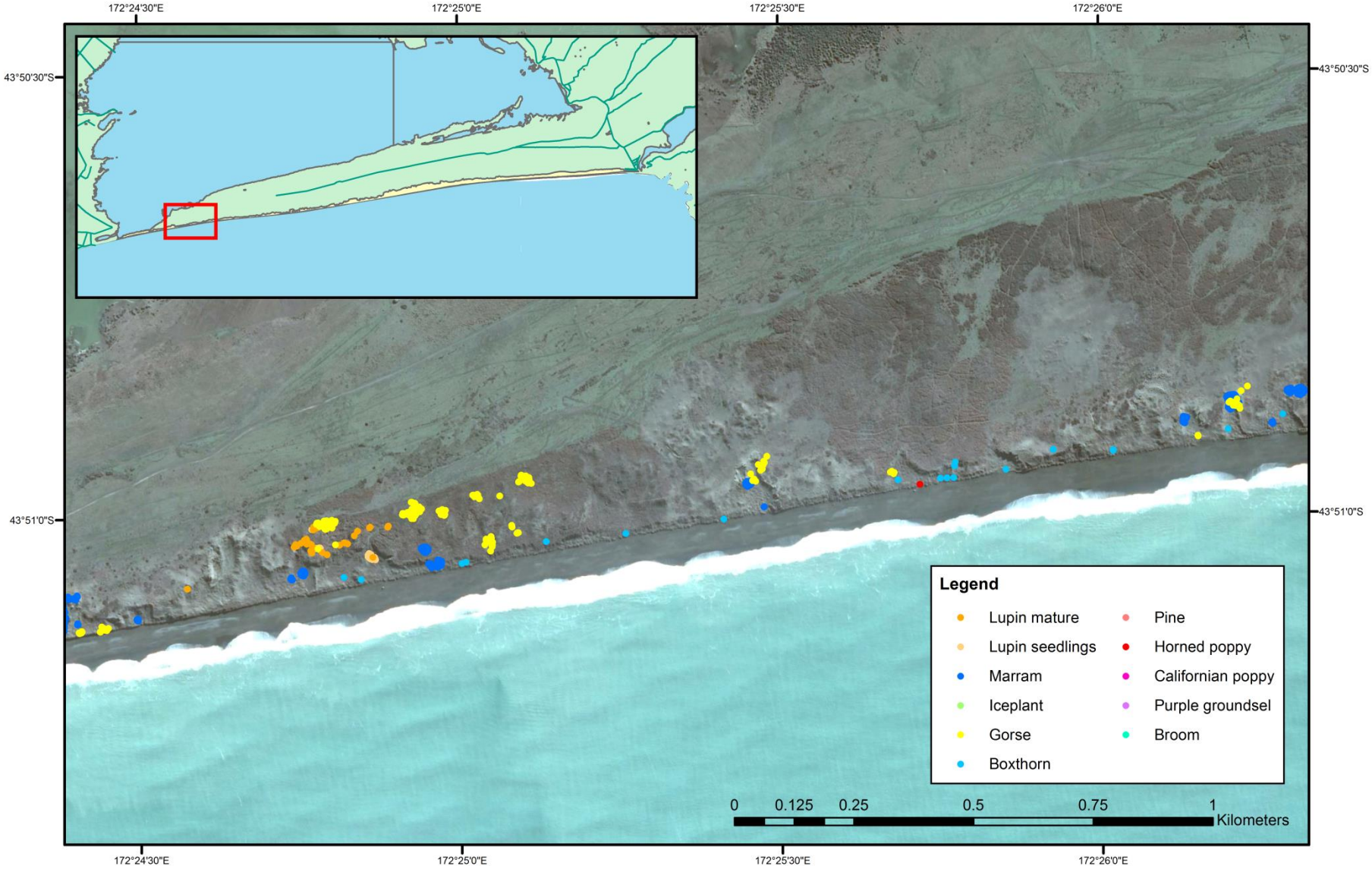
Distribution of broom at Kaitorete Spit in 2015



Appendix B

The surveyed location, from west to east, of all target weed species at Kaitorete Spit, October 2015.


172°23'0"E
172°23'30"E
172°24'0"E
43°51'0"S
43°51'30"S
Legend
Lupin mature
Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
0
0.125
0.25
0.5
0.75
1
Kilometers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172°25'0"E
172°25'30"E
172°26'0"E
43°50'30"S
43°51'0"S
Legend
Lupin mature
Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
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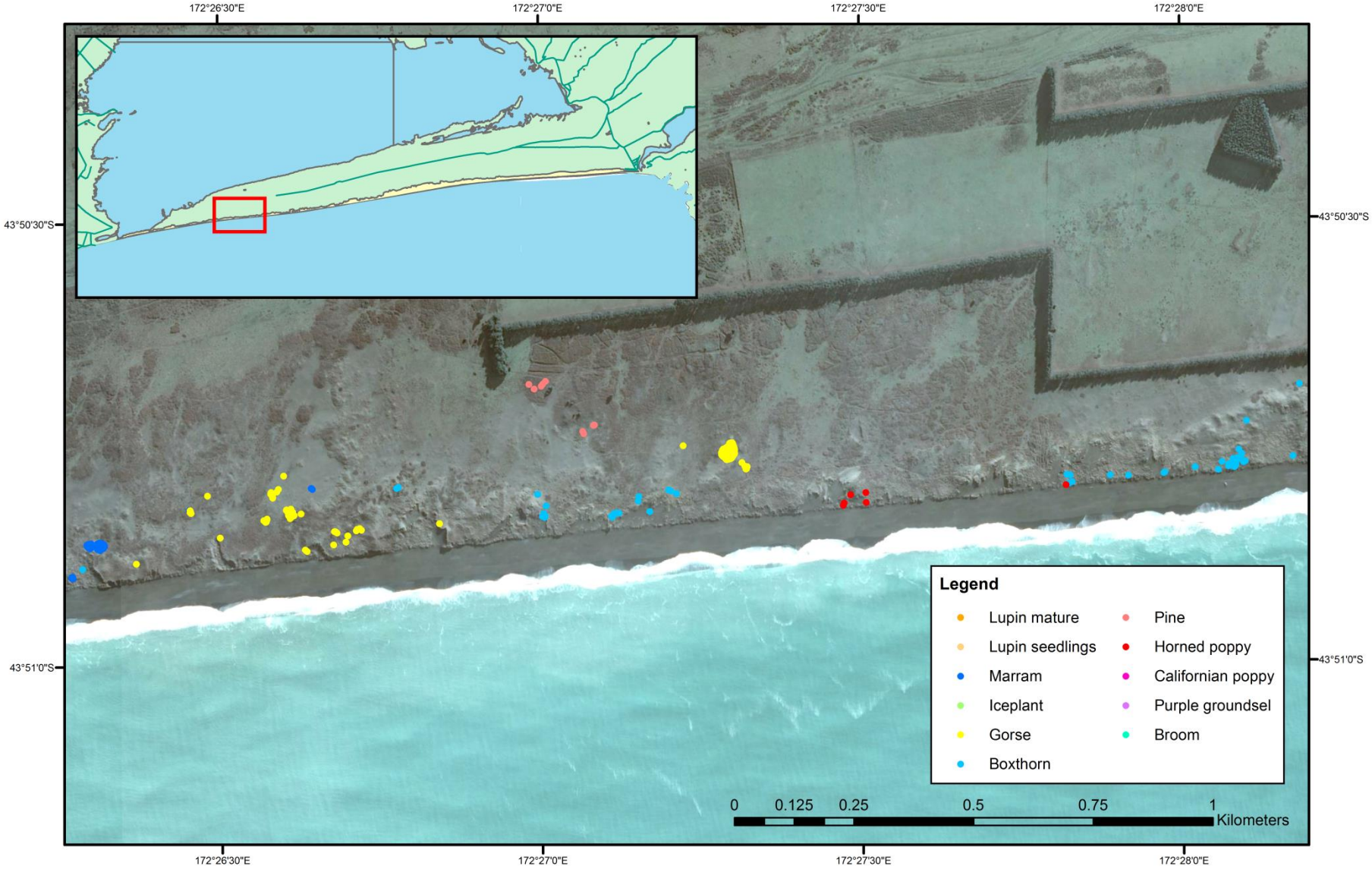
Kilometers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172°27'0"E
172°27'30"E
172°28'0"E
43°50'30"S
43°51'0"S
Legend
Lupin mature
Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
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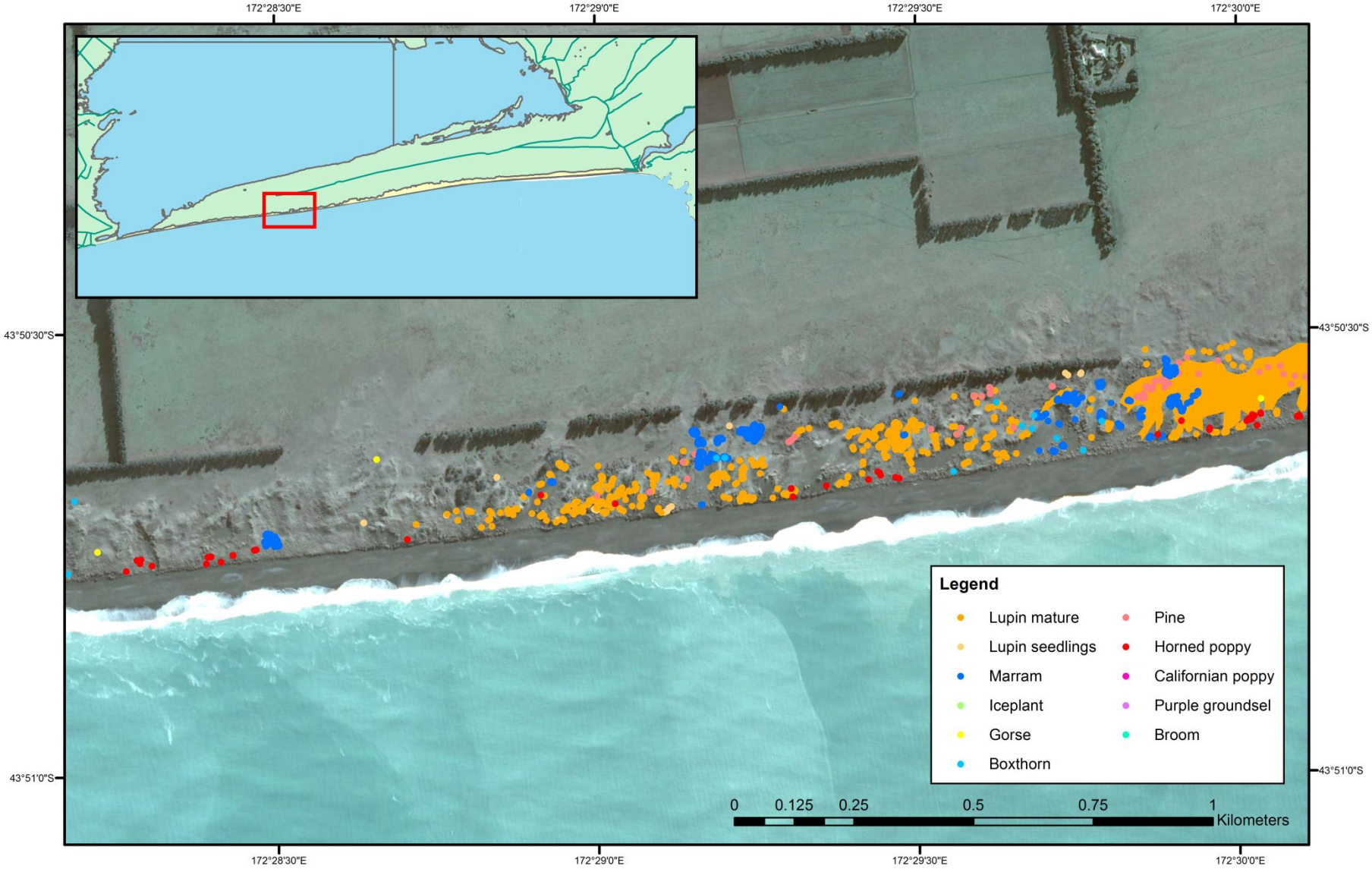
Kilometers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43°51'0"S
Legend
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Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
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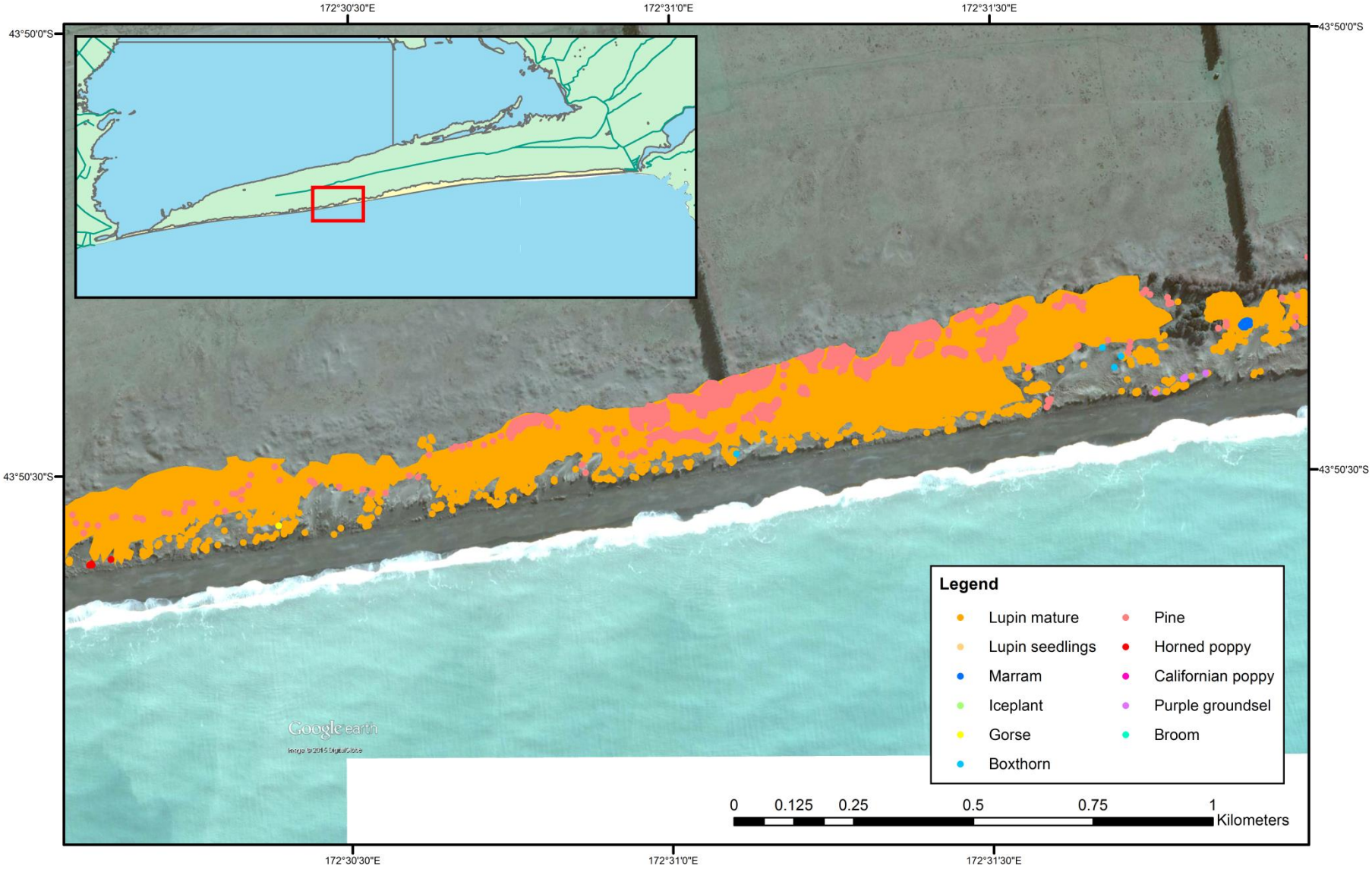
Kilometers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172°31'30"E
43°50'0"S
43°50'30"S
Legend
Lupin mature
Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
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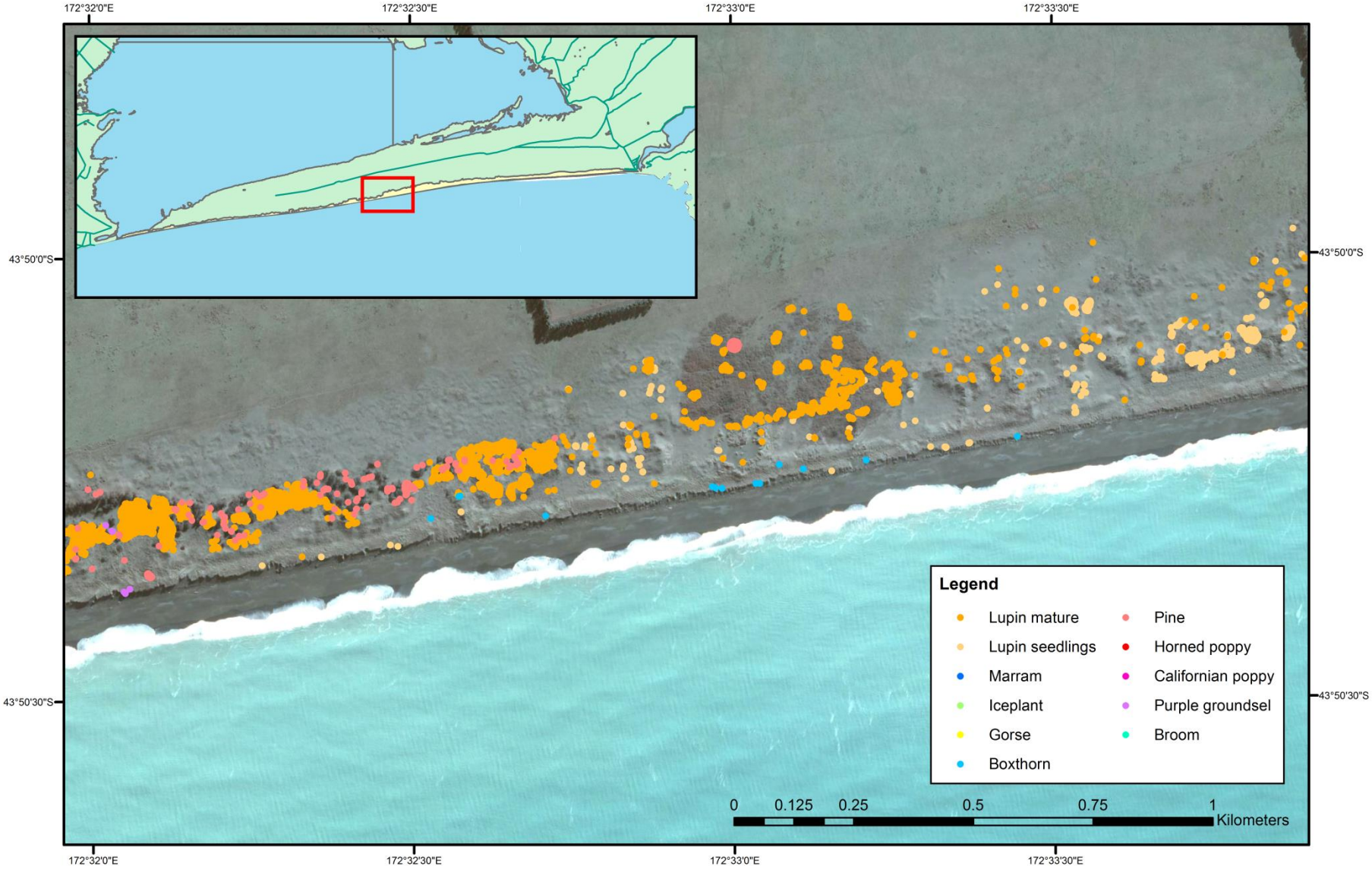
Kilometers
Google earth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Lupin seedlings
Marram
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Gorse
Boxthorn
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Californian poppy
Purple groundsel
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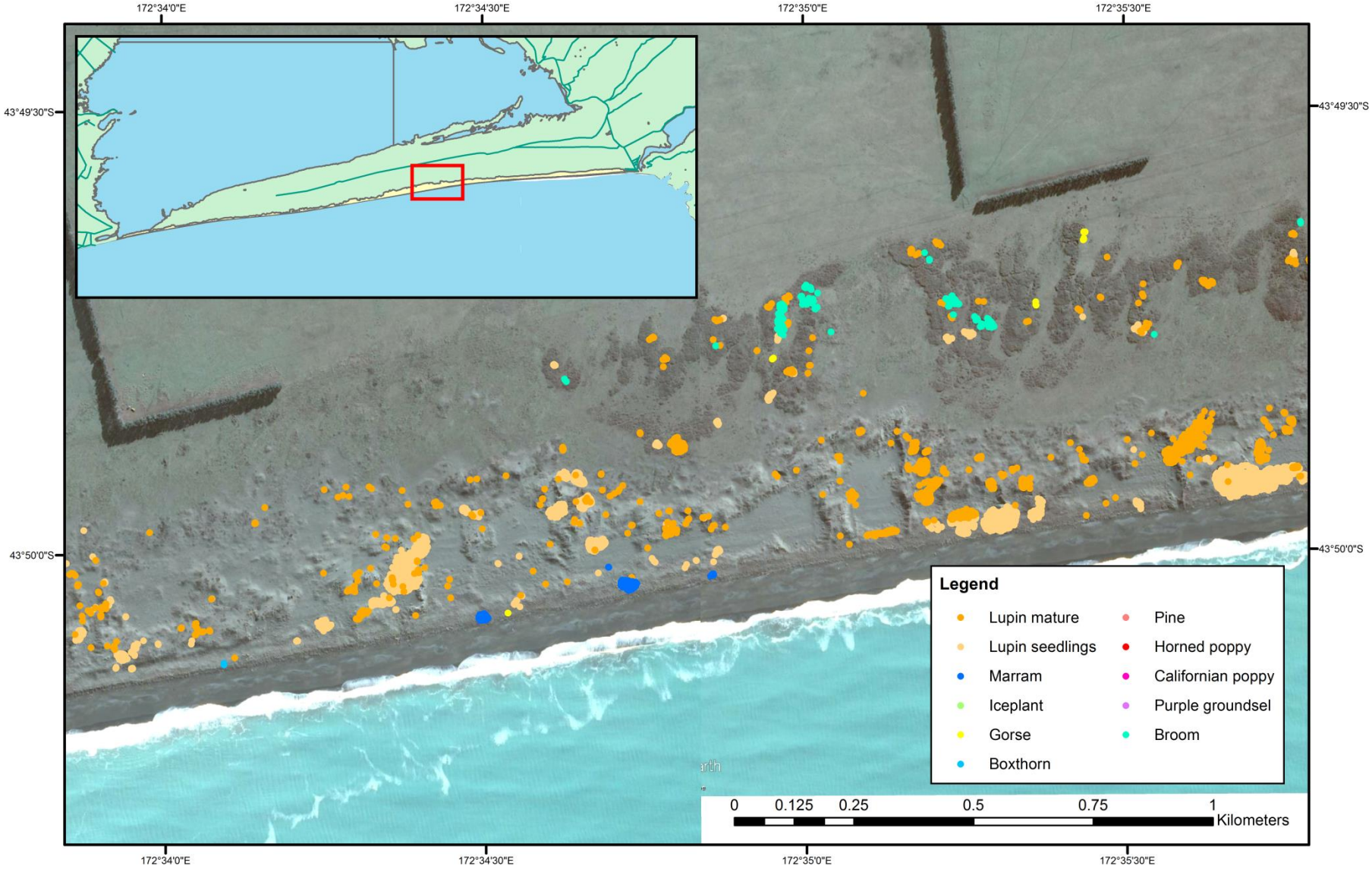
Kilometers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172°35'30"E
43°49'30"S
43°50'0"S
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Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
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Californian poppy
Purple groundsel
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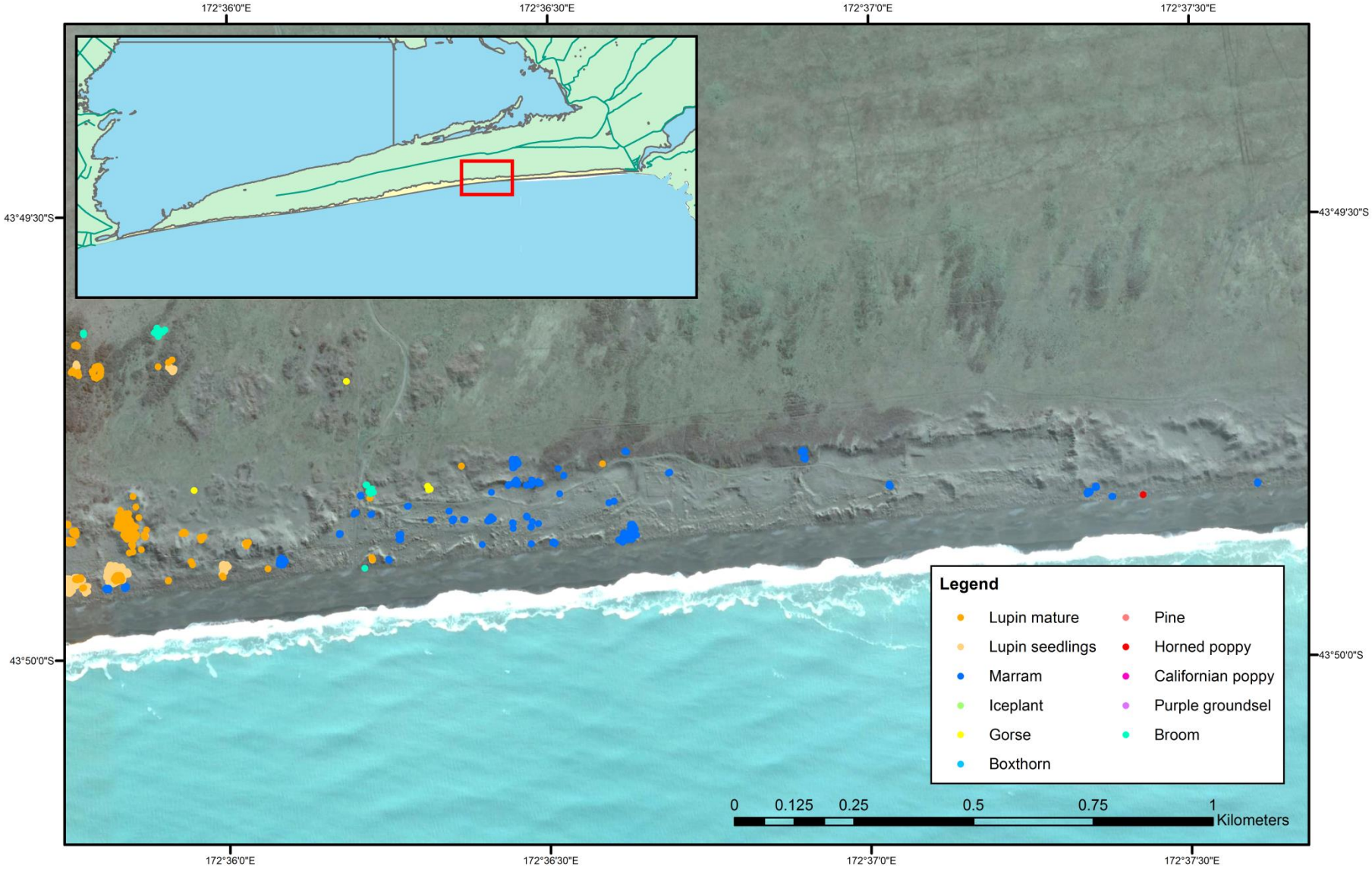
Kilometers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Legend
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Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
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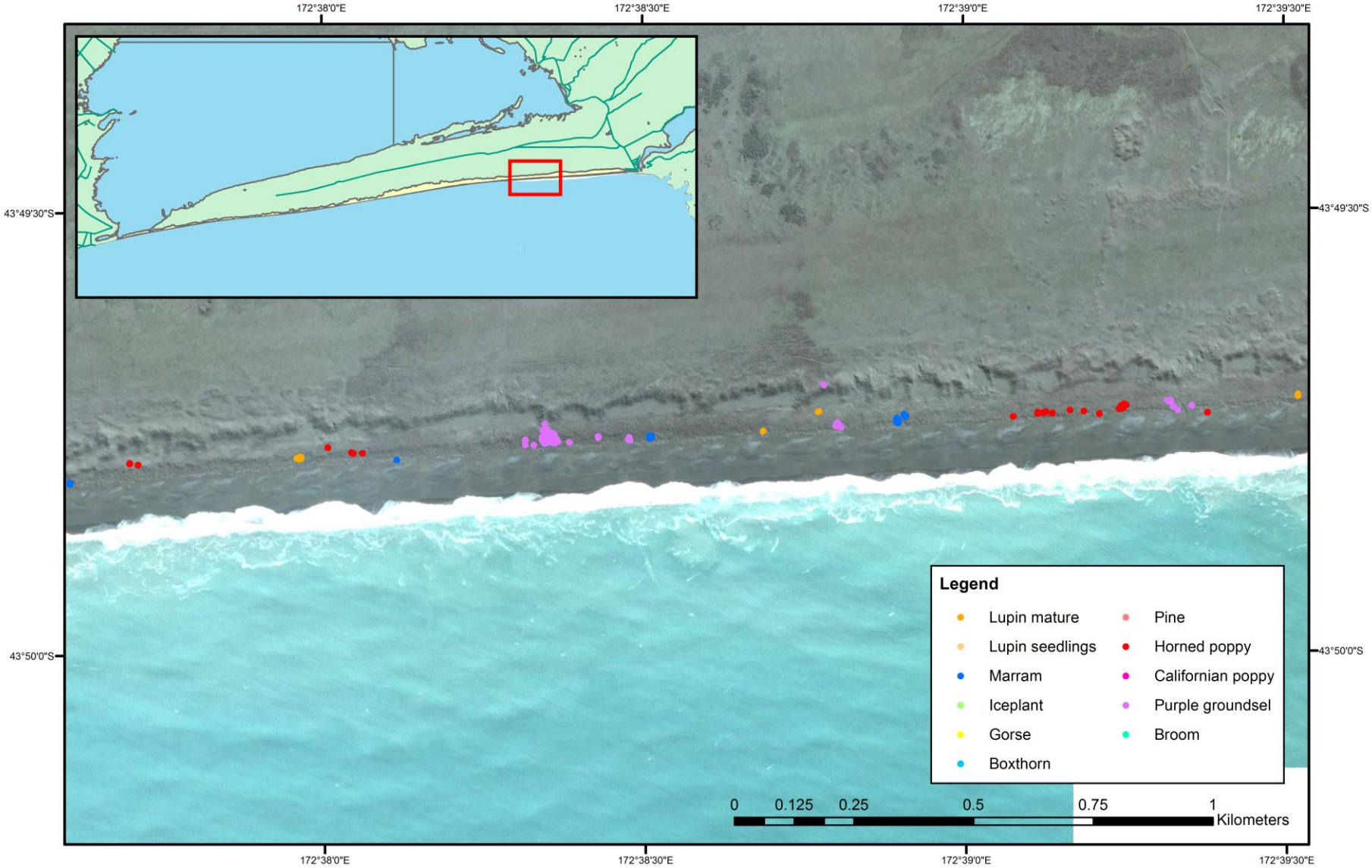
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172°39'0"E
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Legend
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Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
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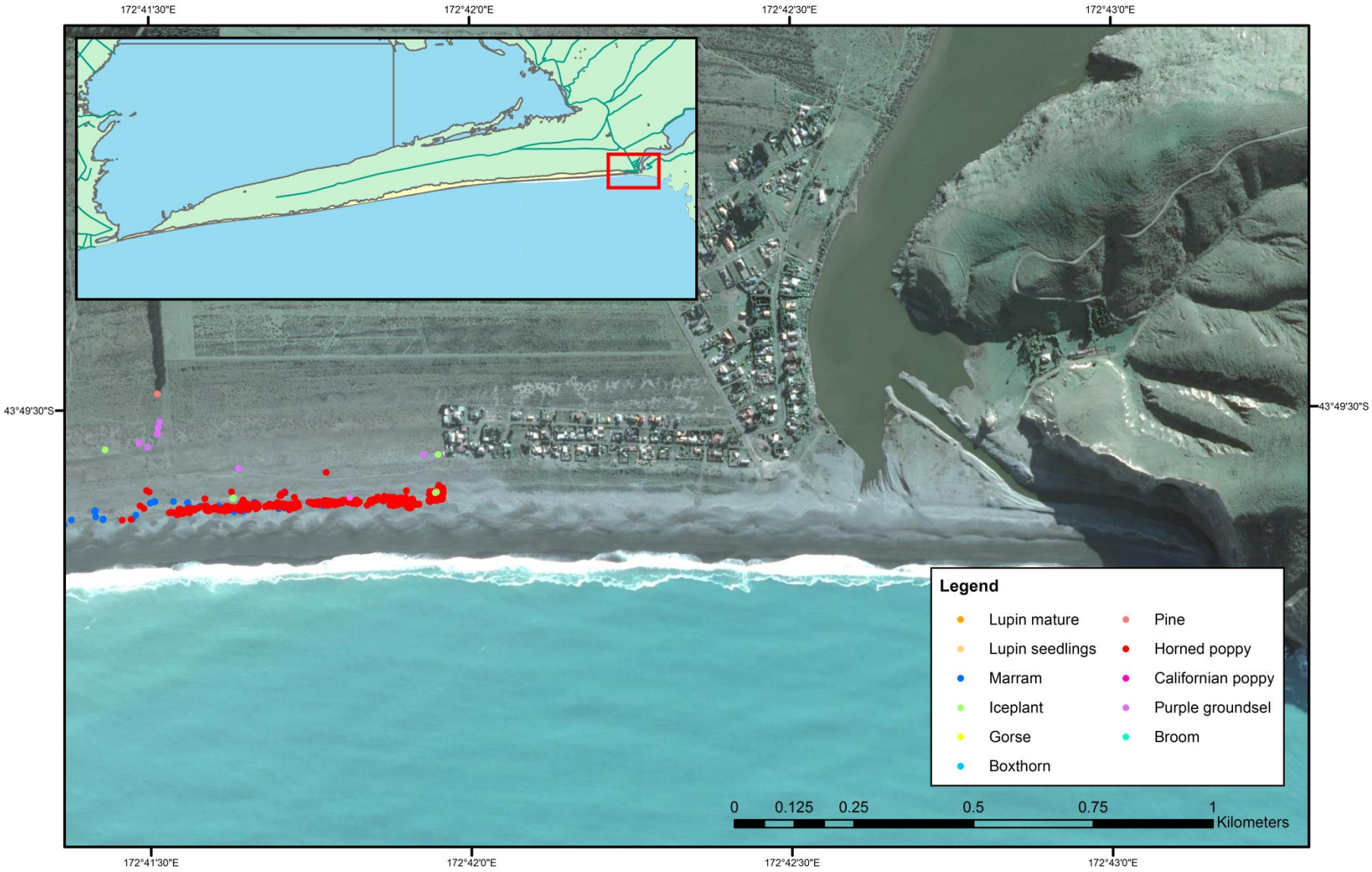
Kilometers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Lupin mature
Lupin seedlings
Marram
Iceplant
Gorse
Boxthorn
Pine
Horned poppy
Californian poppy
Purple groundsel
Broom
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Kilometers