



This discussion paper is/has been under review for the journal Biogeosciences (BG).
Please refer to the corresponding final paper in BG if available.

Recolonization of the intertidal and shallow subtidal community following the 2008 eruption of Alaska's Kasatochi Volcano

S. C. Jewett¹ and G. S. Drew²

¹Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775-7220, USA
²US Geological Survey, Alaska Science Center, 4210 University Drive, Anchorage, AK 99508 USA

Received: 13 November 2013 – Accepted: 21 February 2014 – Published: 7 March 2014

Correspondence to: S. C. Jewett (scjewett@alaska.edu) and G. S. Drew (gdrew@usgs.gov)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Abstract

The intertidal and nearshore benthic communities of Kasatochi Island are described following a catastrophic volcanic eruption in 2008. Prior to the eruption, the island was surrounded by a dense bed of canopy-forming dragon kelp *Eualaria fistulosa* which supported a productive nearshore community. The eruption extended the coastline of the island approximately 400 m offshore to roughly the 20 m isobath. One year following the eruption a reconnaissance survey found the intertidal zone devoid of life. Subtidally, the canopy kelp, as well as limited understory algal species and associated benthic fauna on the hard substratum, were buried by debris from the eruption. The resulting substrate was comprised almost entirely of medium and coarse sands with a depauperate benthic community. Comparisons of habitat and biological communities with other nearby Aleutian Islands and the Icelandic submarine volcanic eruption of Surtsey confirm dramatic reductions in flora and fauna consistent with the initial stages of recovery from a large-scale disturbance event. Four and five years following the eruption brief visits revealed dramatic intertidal and subtidal recolonization of the flora and fauna in some areas. Signs of nesting and fledging of young pigeon guillemots *Cephus columba* suggest that the recovery of the nearshore biota may have begun affecting higher trophic levels. Recolonization or lack thereof was tied to bathymetric changes from coastal and nearshore erosion over the study period.

1 Introduction

The Aleutian Islands are situated on the northern edge of the so-called “Pacific Ring of Fire”, a 40 000-km-long horseshoe-shaped assemblage of continental landmasses and islands bordering the Pacific Ocean basin that contains a large number of active and dormant volcanoes. Of the 27 historically active volcanoes in the Aleutian Islands, nine have had at least one major eruptive event since 1990 (Schaefer et al., 2009). Despite the relatively high frequency of volcanic activity in the Aleutians, the response and

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

subsequent recovery of island ecosystems to volcanic disturbances has been largely unstudied due to the region's isolation. Prior to the Kasatochi eruption, the only ecological studies in the region addressing the effects of volcanic activity on biological systems were done on Bogoslof Island, a remote, highly active volcanic island in the eastern Aleutians. Since emerging from a submarine eruption in 1796, Bogoslof Island has been the site of several avian and marine mammal studies, but no intertidal or subtidal investigations (Merriam, 1910; Byrd et al., 1980; Byrd and Williams, 1994). Bogoslof is similar to the submarine eruption of the Icelandic island of Surtsey, which formed in 1963 (Fridriksson, 1975).

With no confirmed historical eruptions, Kasatochi volcano in the central Aleutian Islands erupted on 7–8 August 2008 and pyroclastic flows and volcanic ash completely covered the island and nearshore marine habitat (Scott et al., 2010; Waythomas et al., 2010a, b). Observations a year following the eruption revealed that virtually all terrestrial and subtidal plant and animal life was eliminated (Drew et al., 2010; Jewett et al., 2010; Sikes and Slowik, 2010; Talbot et al., 2010; Williams et al., 2010).

Scant pre-eruption intertidal and shallow (< 20 m) nearshore benthic information exists around Kasatochi Island. However, numerous intertidal and nearshore dive investigations have been conducted at other Aleutian locations, primarily focusing on the flora and fauna of hard substrates (Lebednik and Palmisano, 1977; O'Clair, 1977; Estes et al., 1989, 2004; Konar, 2000; Reisewitz et al., 2006; Chenelot et al., 2011; Vicknair and Estes, 2012). The recent decline of sea otters (*Enhydra lutris*) throughout the Aleutian archipelago has caused a shift in the rocky nearshore community, from one dominated by kelps to one dominated by sea urchins (*Strongylocentrotus polyacanthus*) (Estes et al., 2010). Dense beds of canopy-forming dragon kelp *Eualaria fistulosa*, were present around Kasatochi prior to the 2008 eruption (see Setting).

Nearshore kelp forest habitats provide forage fish with required nursery areas and cover from predation (Bodkin, 1988; Siddon et al., 2008; O'Conner and Anderson, 2010). Prior to the eruption the nearshore zone supported extensive kelp habitat and a complement of nearshore epibenthic foraging birds including cormorants *Phalacro-*

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

was somewhat conical, initially covered with vascular plants, and with a small lake in the caldera. Breeding seabirds, in particular auklets *Aethia* spp., puffins *Fratercula* spp., and storm-petrels *Oceanodroma* spp. that nested in crevices in talus slopes and rock piles, dominated the island's vertebrate fauna (Williams et al., 2010). A Steller sea lion *Eumetopias jubatus* rookery occurred on the northern side of the island with an estimated population of ~ 1000 animals (J. Williams, AMNWR, personal communication, 2009). Dense beds of canopy dragon kelp *Eualaria fistulosa* were evident around Kasatochi Island, except along the northern shore, before the 2008 eruption (J. Williams and W. Pepper, AMNWR, personal communication, 2009; B. Webster, personal communication, 2010). The status of understory kelps prior to 2008 is nearly unknown, but presumably similar to nearby islands. The eruption initially increased the island's area about 40 % to 7 km² and the diameter about 800 m (Waythomas et al., 2010a, b). The volcanic flows and ash that extended the coastline also buried the kelp beds and associated understory flora and fauna. Since the eruption, the coastline and nearshore community have been subjected to constant erosion and accretion from storms, precipitation, and currents. Due to the logistical challenges posed by studying a remote location with limited access we relied on one or two opportunistic visits per year with variable data collection.

2.2 Radial transects – 2009

Six primary transects that radiated from the caldera to the shore of Kasatochi Island were established for terrestrial sampling (Wang et al., 2010). Intertidal sampling occurred on all transects at approximately the +0.5 m tidal height. At each transect, benthic invertebrates were collected from three 0.06 m² replicate quadrates by sampling to a depth of 10 cm in soft substrates and scraping the surface on hard substrates. The primary transects were extended into the marine environment where offshore nutrient sampling (Drew et al., 2010) and nearshore (10–20 m water depths) benthic sampling/observations occurred aboard the M/V *Tiġlaġ* (Fig. 2) (Jewett et al., 2010). Benthic samples were collected by divers at 10 m depths along secondary transects

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

perpendicular to primary transects (Fig. 3); underwater videos were recorded at 10–20 m depths. Sampling occurred 12–15 June and 10–12 August 2009. Details of the diver sampling methodology are presented in Jewett et al. (2008, 2010) and a sampling layout is shown in Fig. 3. At each sampling point, a set of 3 nested quadrats (1 m × 1 m, 50 cm × 50 cm, and 25 cm × 25 cm in size) were placed on the offshore side of the transect. Within each 1 m² quadrat, a 50 cm × 50 cm (0.25 m²) and a 25 cm × 25 cm (0.06 m²) quadrat was placed for algal and invertebrate sampling, respectively. The abundance and percent cover of algae and macroinvertebrates were recorded within the 1 m × 1 m (1 m²) quadrat. A diver-operated airlift capped with a 0.5 mm mesh bag was used to collect all invertebrates found within the 25 cm × 25 cm quadrat.

The post-eruption Kasatochi benthic community and sediments were compared to two communities previously sampled from nearby Atka and Amlia islands in 2006 and 2007; sampling methods were comparable (Jewett et al., 2008, 2010).

2.3 Diver video – 2009

In June and August 2009 video recordings (1–2 min) made by divers from the 10 m transects were intended to provide semi-quantitative information on habitat characteristics and distribution of major algal and macrofauna taxa. To assist with characterizing the habitat, another diver either recorded on a slate or collected representatives of the dominant mature algae and macrofauna from 1 m on either side of the transect (2 × 25 m). Videos, as well as occasional still photos, were taken with a Canon™ PowerShot S80 digital camera.

2.4 Remote video – 2009, 2012 and 2013

A Splashcam™ camera was deployed from the M/V *Tiġlaġ* in August 2009 to characterize the benthic substrate and community at the 20 m depth along the six primary transects. The Splashcam™ was also deployed from a skiff at 10–20 m depths along

the same transects in June 2009, August 2012 and June 2013. Video segments 2–13 min in duration were recorded on a DVD while the ship or skiff drifted over the site.

2.5 Nearshore marine bird censuses – 2003–2013

Prior to the 2008 eruption Kasatochi supported reproductive populations of cormorants *Phalacrocorax* spp. and pigeon guillemots *Cepphus columba*. Censuses were used to compare numbers of nearshore foraging marine bird predators, hereafter referred to as nearshore marine birds, before and after the eruption. Censuses were conducted from a 4.5 m skiff approximately 100 m offshore, two observers counted all marine birds on the water or flying within 100 m of either side or 200 m in front of the skiff (resulting in a 200-m-wide survey strip). Observations were geolocated using a GPS and their distributions mapped using GIS software. On-shore nest searches were conducted in June of all years following the eruption (2009–2013); however, effort varied due to available time, weather, and terrain.

2.6 Data analyses

ANOVAs were used for comparisons between water temperatures and years, sediment grain size (percent) and study sites, and amphipod abundance (percent) and sites. All percentages were arcsine transformed prior to the ANOVA testing. Statistical significance was set at $p \leq 0.05$. The early state of recovery precluded statistical testing of seabird response in relation to the recovery of their foraging habitat. Instead, we collected and compared census data for nearshore marine birds, compared distributions of nearshore marine birds and kelp habitat, and identified signs of their reproduction. Pre-eruption nearshore marine bird census data provided a baseline for post-eruption comparison.

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

3 Results

3.1 Shoreline geomorphology – 2008–2012

Post-eruption satellite images revealed a changing shoreline (Fig. 4). On 17 September 2008, 3.7 weeks following the eruption, a thick accumulation of volcanoclastic deposits had spread seaward of the pre-eruption coastline (image 9 April 2004), increasing the diameter of the island ~ 0.8 km and resulting in about a 40 % increase in area (Waythomas et al., 2010a). The western shoreline had the greatest offshore expansion, ~ 0.5 km, while most other sectors spread 0.3–0.4 km. Exceptions were the promontories adjacent to Tundering Cove, Whiskey Cove, Sea Lion Spit, and Rye Point, which had little to no offshore extension. Volcanic deposits of predominantly medium and coarse grain sands buried the thick stand of canopy kelp that rimmed most of the island and extended to about 20 m water depths. Also buried were the data logger, located off the east coast in 7–9 m of water, and Shag Rock, about 0.2 km off the pre-eruption southwest shore (Fig. 4).

On 18 April 2009, 9.3 months after the eruption, the shorelines along the east, north, and west were reduced 0.05–0.2 km, with a few exceptions, from the 17 September 2008 image. In contrast, the southeast, south, and southwest shores expanded 0.15–0.25 km seaward (Fig. 4).

By 20 February 2012, 3.6 years post-eruption, the northern shoreline from north of Rye Point to the point north of Oystercatcher Beach had eroded to pre-eruption shoreline proximity. Lesser erosion was evident along the southeast and southwest shores, however, shoreline expansion was evident along the southern shore by as much as 0.1 km, so accretion on this coast grew ~ 0.5 km from the pre-eruption shore (Fig. 4).

3.2 Intertidal community – 2009, 2012, and 2013

In 2009 intertidal sampling occurred on Transects (T) 2, 3, and 5 where the substrate consisted of coarse sand. Since no visible plants or invertebrates were in these sam-

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

ples a decision was made to not sample the remaining intertidal transects, but to focus on the subtidal sampling. In August 2010, 2011 and 2012 intertidal sampling did not occur because of poor weather. Nevertheless, terrestrial samplers made opportunistic qualitative observations of the intertidal zone where they went ashore at rock-rimmed Tundering Cove on the northwest side of the island. In 2010 at approximately +0.4 m tidal height a depauperate intertidal community was observed with a few unidentified barnacles among a thin matt of unidentified diatoms on rocks. In 2011 at a tidal height of approximately +0.4 m this site revealed young ribbon kelp *Alaria marginata* along with green sea hair *Ulva intestinalis* and a red seaweed *Porphyra* sp. in tide pools. Two species of barnacles, *Semibalanus cariosus* and *Balanus glandula*, were most numerous, but a few small blue mussels *Mytilus trossulus*, and limpets were also prevalent. Two size classes of barnacles were apparent, ~ 4 mm and ~ 10 mm base diameters. During 2012 in Tundering Cove at a tidal height of approximately the +0.6 m a robust intertidal community with a well-defined barnacle band above a thick band of ribbon kelp and green sea hair in tide pools was revealed. At Tundering Cove in June 2013 a dense band of ribbon kelp and red algae *Palmaria hecatensis* rimmed the rock wall approximately 1.5 m above the +0.3 m tidal height.

3.3 Canopy kelp – 2009 and 2012

Limited pre-eruption information on the nearshore marine community at Kasatochi exists. Personnel and scientists who visited Kasatochi from the M/V *Tig̃lãx̃* attest that before the 2008 eruption dense beds of canopy-forming dragon kelp *Eualaria fistulosa* were evident around the island, except along the northern shore where slope and water depth limited offshore kelp (Fig. 5a). Aerial reconnaissance in the spring of 2009 determined that the eruption extended the coastline of the island about 400 m, mainly along the south, southeast and southwest shores, to roughly the 20 m isobath (Scott et al., 2010). This expansion of volcanic material covered the kelp beds and associated benthic community that previously occurred there. Surveys from the M/V *Tig̃lãx̃* in August 2009 did not find any canopy kelp along any of the six transects (Jewett et al.,

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2010; Table A1). However, canopy kelp was visible at the water surface in small patches at three locations, off the east (near T2), northwest (near T5), and southwest sides of the island (Fig. 5b). By August 2012, canopy kelp had expanded considerably, particularly on the western (T4), northwest (T5 & T6), and east (near T2) sides of the island (Figs. 2, 5c; Table A1). No canopy kelp was observed along the southern side, where, prior to the 2008 eruption, the kelp was particularly dense. A reconnaissance visit in June 2013 revealed only three small canopy kelp patches (N, E, and SW), however, maximum kelp length is not attained until fall.

3.4 Subtidal community – 2009

Jewett et al. (2010) reported on the nearshore benthic community at Kasatochi 10 and 12 months following the 2008 eruption. Twelve video recordings (by diver and Splashcam™) and one diver observation made within the 20 m isobath revealed little hard substrate on a largely featureless bottom (Table A1). At 10 m, the surficial substrate was dominated by sand, with gravel and a few partially exposed boulders. At 20 m, sand waves, with coarser sand on the wave crests, were evident on Transects 2 and 5, but fines, i.e., mud and fine sand, were more prevalent on Transects 1, 2, 4 and 6. Soft sediment comprised 100% of the substrate within most of the 1 m × 1 m sediment quadrats, except along T3 where boulders and cobbles were encountered.

Sediment samples collected by divers at 10 m depth on five of the six subtidal transects (T1 not sampled due to rough seas) were predominantly medium and coarse grain sands (0.25–1.0 mm). There was no significant difference in the grain size composition (gravel, sand, mud) at the five sampling sites (ANOVA: $df = 4$, $F = 0.012$; $p = 0.99$).

Benthic organisms (infauna and epifauna) were rarely observed by divers or recorded on videos. Holes in, or mounds on the soft substrate, indicative of macrobenthic invertebrates, and large epifaunal invertebrates were absent from the soft substrate. Divers observed a few live barnacles on T6 and a few juvenile fishes on T2 and T6. One large

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

sites where amphipods occurred (ANOVA: $df = 2$, $F = 0.011$, $p = 0.98$). The dominant amphipod family Pontogeneiidae, composed of *Pontogeneia ivanovi*, *P. makarovi*, and *Pontogeneia* sp., comprised 27 to 81 % of the total site abundance.

Because no pre-eruption information on the macrobenthic community at Kasatochi was available for comparison with 2009 data, comparisons were made with data from nearby Atka and Amlia islands (not shown on Fig. 1), in the Andreanof Islands group, with similar depths and soft sediments as sampled at post-eruption Kasatochi. Depths at the two sites were 9 and 14 m, respectively. Although the sediments at these two sites were mostly sands, they were generally finer than at Kasatochi. The faunal abundances at the Atka and Amlia sites were an order of magnitude greater than sites around Kasatochi Island. Furthermore, these sites were mostly dominated by polychaetes, gastropods, and sand dollars, rather than amphipods. These two sites also had evidence of a well-established macrobenthic community, with biotic mounds and holes, and numerous macrobenthic components, like burrowing anemones, polychaetes, hermit crabs, sea urchins, sand dollars, sea stars, and adult and juvenile flatfishes (Jewett et al., 2010).

3.5 Subtidal community – 2012

Filming on 28 August 2012 with the Splashcam™ revealed substantial recovery of the benthic environment from observations made in 2009. Large brown algae, mainly dragon kelp *Eualaria fistulosa*, were present on five of the six transects, i.e., Transects 2, 3, 4, 5, and 6 (Table A1; Fig. 2). The kelp was so dense in places the Splashcam™ often tangled in the kelp. Although coarse sand still dominated, boulders, the substrate for kelp attachment, were considerably more prevalent than in 2009. Furthermore, several of the transect site depths were about 1–5 m deeper in 2012 than in 2009, suggesting the erosion of fine substrate occurred. No sites were shallower. Other observed biota included diatoms and light green algae (T1 at 21 m), red algae (T2 at 10 m), brown alga *Saccharina groenlandica* (T3 at 14 m), barnacles (T6 at 10 m), and three small

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

flatfishes (one Pacific halibut *Hippoglossus stenolepis* and two unidentified) (Table A1; Fig. 2).

Additional evidence of recovery included the presence of feeding pigeon guillemots, young gulls *Larus* sp. and cormorants amid the dragon kelp canopy at T4, 11 m.

5 Additionally, when the data logger was retrieved on 28 August 2012 (deployed 20 June 2012) from a depth of 9 m near T2 (Fig. 2), a large rock was caught in the anchor. Biota attached to the rock included two juvenile kelp *Saccharina* sp., a polynoid scale worm, hydroids, bryozoans, barnacles (~ 10 mm base diameter), and caprellid amphipods.

10 3.6 Subtidal community – 2013

On 17 June 2013 Splashcam™ videos revealed only slight recovery of the benthic environment at a few sites in comparison from 2012 observations. Most sites revealed little or no additional recovery due to recent burial or removal of sand. T4 at 10 m, a site among canopy dragon kelp, had denser dragon kelp and understory kelps *S. groenlandica* and *Alaria marginata*, as well as amphipods. T3 at 17 m had more *S. groenlandica*. T1 at 22–30 m and T2 at 12 m had germling brown algae. Compared to 2012 water depths remained the same at five study sites (T2 at 12 and 20 m, T5 at 10 m, and T6 at 10 and 20 m), was deeper at four sites (T1 at 22–30 m, T3 at 17.7 and 24.4 m, and T4 at 17 m), and shallower at three sites (T3 at 10 m, T4 at 10 and 20 m) (Table A1; Fig. 2).

20 3.7 Nearshore Foraging Birds – 2003–2013

Following the eruption cormorants *Phalacrocorax* spp., though never observed in large numbers around the island, became rare (Fig. 6). Although post-eruption sampling was limited to a single June census, the most recent (June 2013) had the highest count of cormorants since the eruption. To date there is no evidence that cormorants are breeding on the island.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Pigeon guillemots *Cephus columba* showed a different pattern than the cormorants. Relatively common prior to the eruption, the first post-eruption count of pigeon guillemots in June 2009 was the highest recorded. The census numbers then dropped in the two subsequent counts (2012 and 2013) to the lowest numbers recorded (Fig. 7).

5 A single pigeon guillemot nest was discovered on the east side of the island in 2010, and evidence of successful fledging was noted in August 2011 (1 juvenile) and 2012 (2 juveniles) on the west side of the island.

4 Discussion

10 Although no pre-eruption intertidal investigations occurred on Kasatochi Island, the intertidal community there was presumably similar to that of other islands in the central Aleutians. Lebednik and Palmasino (1977) and O'Clair (1977) provided extensive descriptions of the intertidal communities around Amchitka Island. Algae that dominated the littoral zone of 0 to +0.8 m tidal height included Rockweed *Fucus distichus*, the *Saccharina* (*Hedophyllum sessile*) zone that contained six associations (*Saccharina*, *Ulva*, *Analipus*, *Corallina*, *Halosaccion*, and *Iridaea*), and *Alaria*. The sublittoral zone (0 to -3 m) was dominated by *Laminaria* spp., but primarily *L. longipes* (Lebednik and Palmasino, 1977). O'Clair (1977) listed over 365 invertebrate species in the littoral and sublittoral zone and identified three invertebrate communities according to their dominant macrophytes, the *Laminaria* community, the *Alaria-Saccharina* community, and the *Halosaccion-Fucus* community. The invertebrates in these communities were mostly inconspicuous.

15 Intertidal sampling was initiated at Kasatochi in 2009, but because of the new and unstable shoreline no life was found. The intertidal zone for most of the island has been largely in transition since the eruption, with shorelines alternating in accretion and erosion (see Fig. 4), similar to an active island volcano in Italy (Romagnoli et al., 2006). In hindsight, it would have been better to establish quantitative intertidal monitoring only on the areas dominated by hard substrates, like Tundering Cove. But, this would

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

have required deviating from sampling on the six transects. The only intertidal data available (qualitative) was limited to a few opportunistic photographs at Tundering Cove. These photographs from +0.3 to +0.6 m tidal height on rock substrate transitioned from a few barnacles among diatom mats in August 2010, to young ribbon kelp *Alaria marginata*, green sea hair *Ulva intestinalis*, a red seaweed *Porphyra* sp., barnacles *Semibalanus cariosus* and *Balanus glandula*, and small blue mussels *Mytilus trossulus* in August 2011, to a well-defined barnacle band above a thick band of ribbon kelp and green sea hair in tide pools in August 2012, to a dense band of ribbon kelp and red alga *Palmaria hecatensis* in June 2013. We anticipated the intertidal community on hard substrate will continue to increase in diversity and stabilize within a few years, as demonstrated on the submarine volcano Surtsey (Jónsson and Gunnarsson, 1982). But, the community on shorelines composed of soft substrates will not occur until land and coastal erosion equilibrates.

Following nearly a century of sea otter range expansion and population growth, sea otter numbers began to decline about 1990 across the Aleutian Islands (Doroff et al., 2003), generally causing an ecosystem phase shift from a kelp-dominated to an urchin-dominated subtidal community (Estes et al., 2004). While today the Aleutians are generally in an urchin-dominated state (i.e., urchin barren) (Estes et al., 2010), canopy kelp beds, primarily the annuals *Eualaria fistulosa* and *Nereocystis luetkeana*, as well as numerous species of understory algal species, e.g., the annual *Cymathaere triplicata*, and the perennials *Saccharina groenlandica*, *Laminaria* spp., *Agarum* spp., and *Thalasiophyllum clathrus*, still occur in some areas of the archipelago (Konar and Estes, 2003; Lindeberg and Lindstrom, 2010; Dasher et al., 2012).

Alaska Maritime National Wildlife Refuge personnel obtained information on the kelp community of Kasatochi Island prior to the eruption from surface observations while aboard the *M/V Tiglax̄*. This vessel makes annual sojourns to the island, as well as elsewhere in the Aleutians. Refuge personnel maintained that in years leading up to the 2008 eruption dense beds of canopy-forming dragon kelp *E. fistulosa*, were prevalent around Kasatochi, except along the northern shore where deep waters limit the canopy

(J. Williams and W. Pepper, AMNWR, personal communication, 2009). Additionally, robust canopy kelp was visible around most of the island 19 July 2008, 18 days prior to the eruption on 7 August (B. Webster, personal communication, 2010).

Pre-eruption information of subtidal community is from two dives from the M/V *Tiġla* that were made on 3 September 2002 along the east side of Kasatochi (R. Lauth, NOAA, personal communication, 2009). The first dive (52°10.250' N 175°29.395' W) was approximately 200 m north of our 2009 Transect 2, 10 m site (Fig. 2). On the first dive, at a depth of ~ 9 m, video recording revealed a dense canopy of *E. fistulosa* at the surface. At this depth, where the temperature data logger was retrieved, the hard substrate was covered by *E. fistulosa* and dense understory of the brown alga *Cymathaere triplicata*. On the second dive, ~ 200 m WNW of the data logger position, divers descended a wall to 25 m. Brown algae *Agarum turneri* and *Saccharina groenlandica* were present along the upper portion of the wall. Algae deeper than ~ 20 m were the green alga *Codium ritteri* and encrusting red coralline algae, *Clathromorphum nereostratum* and *Lithothamnion* spp. The wall and the floor at the base of the wall were completely covered with sessile organisms such as sponges, sea anemones, gorgonian corals (e.g., *Paragorgia* spp.), hydroids, bryozoans, rock jingles *Pododesmus macrochisma*, barnacles, and tunicates. Mobile epifauna consisted of a scale crab *Placetrion wosnessenskii*, sea stars (*Henricia* spp. and *Solaster* sp.), brittle stars, and sea urchins *Strongylocentrotus polyacanthus*. Numerous black *Sebastes melanops* or dusky rockfish *S. ciliatus* were noted along the dive, especially below 20 m. Based on widespread changes in benthic community structure in recent years (Estes et al., 2010), it is difficult to predict what the more widespread subtidal community at Kasatochi looked like just prior to the eruption. Nevertheless, whatever dominated the nearshore community around Kasatochi prior to the eruption was mostly destroyed by the 2008 eruption.

Extension of the shoreline to 400 m offshore to a pre-eruption depth of ~ 20 m buried the algal community with mainly medium and coarse sands. In all likelihood, the three small patches of canopy kelp observed in August 2009 were the only sea surface rem-

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

nants of the once robust *Eualaria fistulosa* community that surrounded most of the island. This kelp can attain lengths up to 25 m (O'Clair and Lindstrom, 2000), and it is likely that some portions of the kelp community were not completely buried, especially along the outer margin of the *Eualaria* zone. While video recordings approximately a year after the eruption further underscored the near complete elimination of kelps, it did reveal isolated kelp remnants. Recordings at 12 locations along transects revealed relatively small (< 2 m) algal plants at a few locations where the top of boulders were protruding through the soft substrate. The kelp *E. fistulosa* mainly dominated at 14 m on T3 and *Saccharina groenlandica* dominated at 10–12 m on T4. That some fertile *S. groenlandica* was observed indicates some understory kelps survived the eruption. The absence of hard substrate is apparently the major factor limiting kelp recolonization around Kasatochi Island. Studies in temperate systems have shown that algal communities can recover to previous densities within one year of denuding (Foster, 1975; Bertness et al., 2004). In situations where algal communities are buried, recovery is entirely dependent upon the rate of sediment erosion. There is no information on the depth of the overlaying subtidal fines, the erosion rate of subtidal fines by ocean currents, and the erosion rate of terrestrial fines on Kasatochi (from land to sea). Little information exists on currents around Kasatochi or through the closest passes, Fenimore and Atka, but net northerly current speeds through Seguam Pass (east of Kasatochi) and Tanaga Pass (west of Kasatochi) are moderate (20–25 cm s⁻¹) (Stabeno et al., 2005). Current velocities necessary to erode medium and coarse sands (0.25–1.0 mm) are about 20 cm s⁻¹ and greater (Hjulström, 1939). Thus, if currents, especially the tidally-driven ones, are > 20 cm s⁻¹ around Kasatochi it may not be long before they erode the subtidal fines down to hard substratum. This would result in increased hard substrate in the nearshore environment that would enable a diverse algal community to become established again.

Another important component of the subtidal community that presumably was buried by the eruption was the long-lived and slow-growing red crustose coralline algae (Frantz et al., 2005; Halfar et al., 2007). In the Aleutian Islands, red crustose coralline

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

algae (*Clathromorphum nereostratum* and *Lithothamnion* spp.) are widespread in the low intertidal and shallow subtidal regions, and cover most available hard substrates (Chenelot et al., 2011). Crustose coralline algae were observed at one location near Kasatochi in 2002, as noted above, and it is thought to have been pervasive in the nearshore zone based on observations made during Aleutian surveys in 2006–07 (Chenelot et al., 2011; Dasher et al., 2012). Subtidal habitats dominated by crustose coralline algae are often associated with sea urchin-barren grounds and regarded as supporting limited invertebrate communities, especially compared to the adjacent kelp forests. Despite the desolate appearance of crustose habitats, the interstitial spaces of the crustose environments support faunal communities as diverse and abundant as those found in rich kelp forests (Chenelot et al., 2011). Thus, the loss of this habitat is viewed as significant as the loss of the foliose algal community. It is unknown how long it will take for this crustose community to recover when suitable hard substrate is re-exposed by erosion.

Subtidally around Kasatochi, the newly deposited sand substrate was largely devoid of life, since video recordings revealed only barnacles (T6 at 10 m) and no mounds or holes formed by infauna. The dominant macrofaunal species present were motile crustaceans, such as amphipods, that presumably moved into the devastated area from outer unaffected regions. This is in contrast to the Atka and Amlia sites with similar depth and substrate (Jewett, unpublished). Sand communities in the latter region were well established and showed no effects of physical or biological disturbance. They were characterized by high macrobenthic diversity and abundance with dominant faunal components (i.e., polychaetes, gastropods, sand dollars) less motile or sessile than the amphipods found at Kasatochi. Numerous investigators have found amphipods among the first opportunistic species on soft substrates following disturbances (e.g., Oliver et al., 1980; VanBlaricom, 1982; Oliver and Slattery, 1985; Jewett et al., 1999). VanBlaricom (1982) discovered that shallow sand sites disturbed by digging rays were characterized by low macroinvertebrate abundance, but four families of tube-dwelling and burrowing amphipods dominated. Benthic amphipods (13 genera

including tube-dwelling corophiids and burrowing oedicerotids) were among the dominant early colonizing taxa at sandy locations subjected to placer gold mining in Norton Sound, Alaska (Jewett et al., 1999). Little is known about the life history of the amphipods in the family Pontogeneiidae that dominated near Kasatochi, but this family is reported to be a nestler (Yu et al., 2002) and a free surface dweller that feeds as a herbivore, surface detritivore, and carnivore (Biernbaum, 1979). Diatom films or mats were pervasive in the nearshore zone around Kasatochi, and the pontogeneiid amphipods appear to have been the first grazers to utilize this algal resource (Jewett et al., 2010).

Since no post-eruption information on eruption effects or recolonization of nearshore communities on other Aleutian volcanic islands are available, comparisons are made between this study and the volcanic island of Surtsey, off the coast of Iceland. During the ~ 3.5 year volcanic eruption of Surtsey (1963–1967), the cinder cone built up from a water depth of 120 m and eventually covered an area of 6.5 km², of which 2.8 km² were above water to a height of 172 m (Fridriksson, 1975, 2006). Smaller satellite volcanoes were added to the submarine base of the Surtsey structure. During the later period of volcanic activity ash flowed down and destroyed all benthic organisms on the sea floor. Ash reached as far out as 1.8 km off the island, where a thin layer of ash was deposited over a layer of mud. The immediate effects of the eruption on the temperature and nutrient composition of seawater were negligible and there was no effect on salinity.

One element of the algal community around Kasatochi bears resemblance to the first stages of algal settlement around Surtsey. Pioneers of the marine benthic algae that colonized Surtsey 21 months after the island emerged in 1963 were composed only of diatoms *Navicula mollis* and *Nitzschia bilobata* and one species of filamentous green alga *Urospora penicilliformis* (Jónsson, 1967). We also found the first algae colonizers off Kasatochi 10–12 months after the eruption to be unidentified diatoms, mixed with *Urospora* spp., along with young brown (Alariaceae) algae, *Eualaria fistulosa* and *Saccharina* spp., and red alga *Porphyra* spp. It was not until nearly three years after Surtsey emerged did any brown algae (Alariaceae) appear (Jónsson, 1968); four years

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

for red algae (*Porphyra* spp.) (Jónsson, 1970). The number of benthic algae discovered growing on Surtsey three and four years later were 17 and 27 species, respectively. By 1971, seven years after Surtsey's first eruption, about 40 benthic algal species were found (Jónsson and Gunnarsson, 1982).

5 As for the first observed benthic marine fauna around Surtsey (autumn 1967), at least 12 taxa were found in the littoral zone that was dominated by lamellibranch bivalves and barnacles (Sigurdsson, 1968). Subtidally to 20 m depths divers found at least 21 taxa that were dominated by juvenile bivalves, principally *Mytilus edulis* and *Anomia squamula* around the 20 m depth zone (Sigurdsson, 1968). Three amphipod species were
10 found near 20 m, but not identified or quantified. Presumably amphipods at Kasatochi were opportunists derived from the remnants of the kelp bed within and/or immediately outside the devastated area. No such kelp was available at the newly formed Surtsey for three years (Jónsson, 1968).

15 Prior to the 2008 eruption, Kasatochi Island provided extensive nesting habitat for a range of marine birds, including those associated with shallow nearshore habitats (Drew et al., 2010). Nearshore censuses of epibenthic foraging marine birds, i.e., cormorants and pigeon guillemots, before and after the 2008 eruption suggest that these birds have persisted, though in lower numbers, on and around the island since the eruption. We speculate that the high number of pigeon guillemots observed during the
20 June of 2009 census may have been due to a combination of fidelity to the island for nesting and a lack of nesting sites in that first year post-eruption. Given the short foraging range of nesting pigeon guillemot (Gaston and Jones, 1998), the discovery of a pigeon guillemot nest in 2010 and the sighting of fledged young in 2011 and 2012 suggest that shallow epibenthic prey have recovered around Kasatochi to levels sufficient to support a limited reproductive population. On Surtsey, black guillemots *Cephus grylle* were observed nesting three years after the cessation of volcanic activity
25 (Peterson, 2009). Given the short foraging range of nesting *Cephus* spp. (Gaston and Jones, 1998; Ronconi and St. Clair, 2002) it appears that their shallow epibenthic prey

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



recovered or developed rapidly around Kasatochi and Surtsey respectively, to levels sufficient to support a limited reproductive population.

In conclusion, the 2008 eruption of Kasatochi Island resulted in catastrophic change to marine habitats and the near complete loss of biological communities surrounding the Island with a few relict species surviving. Biological legacies, which result from organisms that survive a disturbance, can favor deterministic processes in community assembly and improve predictions of successional trajectories (Walker et al., 2013). The rocky reef habitats that presumably were dominated by sea urchins and canopy kelp prior to the eruption were replaced by a new substrate of medium and coarse sands dominated by benthic amphipods. There is sound evidence that the erosion process is continuing, as demonstrated by greater depths at some stations and the emergence of boulders. These changes have led to greater understory and canopy algal colonization, and increases in benthic fauna that have begun to affect higher trophic levels, i.e., marine birds, the top predators in this ecosystem.

Acknowledgements. We thank the North Pacific Research Board (Project # 923) and the US Geological Survey Alaska Science Center for funding this study. We also thank the crew of the US Fish and Wildlife Service M/V *Tiglaġ* and US Geological Survey (USGS) Research Divers Sandra Baldwin and George Esslinger and UA Divers Héloïse Chenelot and Max Hoberg for their support in field operations. We thank Tony DeGange, Alaska Science Center, and Vernon Byrd, USFWS, for organizing the Kasatochi eruption science program; Jeff Williams, Alaska Maritime National Wildlife Refuge, for providing the water temperature data; Christopher Nye, Alaska Volcano Observatory, for providing aerial maps and coastal outlines of Kasatochi; Robert L. Lauth, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration (NOAA), for providing a video on the pre-eruption benthic community; and Mandy Lindberg, Alaska Fisheries Science Center, NOAA, for providing help with the algal identifications. Bob Webster provided photos of the kelp canopy prior to the eruption. Finally, we thank Tony DeGange, Karen Oakley, and George Esslinger of USGS and Héloïse Chenelot of UAF and two anonymous reviewers for their helpful reviews. Satellite images are (c) DigitalGlobe and used courtesy of the Alaska Volcano Observatory. Images shown were acquired on 9 April 2004 (QuickBird), 18 April 2009 (WorldView-1), and 20 February 2012 (WorldView-2). Mention of

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

trade names or commercial products does not constitute endorsement or recommendation for use.

References

- Ainley, D. G., Anderson, D. W., and Kelly, P. R.: Feeding ecology of marine cormorants in south-western North America, *Condor*, 83, 120–131, 1981.
- Bertness, M. D., Trussell, G. C., Ewanchuk, P. J., Silliman, B. R., and Crain, C. M.: Consumer-controlled community states on Gulf of Maine rocky shores, *Ecology*, 85, 1321–1331, 2004.
- Biernbaum, C. K.: Influence of sedimentary factors on the distribution of benthic amphipods of Fishers Island Sound, Connecticut, *J. Exp. Mar. Biol. Ecol.*, 38, 201–223, 1979.
- Bodkin, J. L.: Effects of kelp forest removal on associated fish assemblages in central California, *J. Exp. Mar. Biol. Ecol.*, 117, 227–238, 1988.
- Byrd, G. V. and Williams, J. C.: Status and trends of seabirds and marine mammals at Bogoslof Island, Alaska, a National Natural Landmark, US Fish and Wildlife Service Report to the National Park Service under Interagency Agreement No. 9700-4-9025. AMNWR 94/10, 9 pp., 1994.
- Byrd, G. V., Divoky, G. J., and Bailey, E. P.: Changes in marine bird and mammal populations on an active volcano in Alaska, *Murrelet*, 61, 50–62, 1980.
- Chenelot, H., Jewett, S. C., and Hoberg, M. K.: Macrobenthos of the nearshore Aleutian Archipelago, with emphasis on invertebrates associated with *Clathromorphum nereostratum* (Rhodophyta, Corallinaceae), *Mar. Biodivers.*, 41, 413–424, 2011.
- Dasher, D. H., Lomax, T., and Jewett, S. C.: Alaska Monitoring and Assessment Program 2006 and 2007 Aleutian Islands Coastal Survey Statistical Summary, Alaska Department of Environmental Conservation, Division of Water, Water Quality Standards, Assessment and Restoration, Fairbanks, AK, DEC AKMAP Aleutian 2006/2007, 2012.
- Doroff, A. M., Estes, J. A., Tinker, M. T., Burn, D. M., and Evans, T. J.: Sea otter population declines in the Aleutian archipelago, *J. Mammal.*, 84, 55–64, 2003.
- Drent, R. H.: Breeding biology of the Pigeon Guillemot, *Cephus columba*, *Ardea*, 53, 99–160, 1965.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Drew, G. S., Dragoo, D. E., Renner, M., and Piatt, J. F.: At-sea observations of marine birds and their habitats before and after the 2008 eruption of Kasatochi Volcano, Alaska, *Arct. Antarct. Alp. Res.*, 42, 325–334, 2010.

Estes, J. A., Duggins, D. O., and Rathbun, G. B.: The ecology of extinctions in kelp forest communities, *Conserv. Biol.*, 3, 252–264, 1989.

Estes, J. A., Danner, E. M., Doak, D. F., Konar, B., Springer, A. M., Steinberg, P. D., Tinker, M. T., and Williams, T. M.: Complex trophic interactions in kelp forest ecosystems, *B. Mar. Sci.*, 74, 621–638, 2004.

Estes, J. A., Tinker, M. T., and Bodkin, J. L.: Using ecological function to develop recovery criteria for depleted species: sea otters and kelp forests in the Aleutian archipelago, *Conserv. Biol.*, 24, 852–860, doi:10.1111/j.1523-1739.2009.01428.x, 2010.

Foster, M. S.: Algae succession in a *Macrocystis pyrifera* forest, *Mar. Biol.*, 32, 313–329, 1975.

Frantz, B. R., Foster, M. S., and Riosmena-Rodriguez, R.: *Clathromorphum nereostratum* (Corallinales, Rhodophyta): the oldest Alga?, *J. Phycol.*, 41, 770–773, 2005.

Fridriksson, S.: Surtsey, Halsted Press, John Wiley & Sons, New York, 198 pp., 1975.

Fridriksson, S.: Surtsey: Ecosystems Found, University of Iceland Press, Reykjavik, 112 pp., 2006.

Gaston, A. J. and Jones, I. L.: *The Auks*, Oxford University Press, Oxford, UK, 1998.

Halfar, J., Steneck, R., Schöne, B. R., Moore, G. W. K., Joachimski, M., Konz, A., Fietzke, J., and Estes, J.: Coralline alga reveals first marine record of subarctic North Pacific climate change, *Geophys. Res. Lett.*, 34, L07702, doi:10.1029/2006GL028811, 2007.

Hjulström, F.: Transportation of detritus by moving water. (Part 1. Transportation), in: *Recent Marine Sediments*, edited by: Trask, P. D., Dover Publications Inc., New York, 5–31, 1939.

Jewett, S. C., Feder, H. M., and Blanchard, A.: Assessment of the benthic environment following offshore placer mining in Northeastern Bering Sea, *Mar. Environ. Res.*, 48, 1–32, 1999.

Jewett, S. C., Brewer, R., Chenelot, H., Clark, R., Dasher, D., Harper, S., and Hoberg, M. K.: Scuba techniques for the Alaska Monitoring and Assessment Program (AKMAP) of the Aleutian Islands, Alaska, in: *Diving for Science 2008*, Proceedings of the 27th American Academy of Underwater Sciences Symposium, edited by: Bruggeman, P. and Pollock, N. W., Dauphin Island, AL, AAUS, 71–89, 2008.

Jewett, S. C., Bodkin, J. L., Chenelot, H., Esslinger, G. G., and Hoberg, M. K.: The nearshore benthic community of Kasatochi Island, one year after the 2008 volcanic eruption, *Arct. Antarct. Alp. Res.*, 42, 315–324, 2010.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

- Jónsson, S.: Further settlement of marine benthic algae on the rocky shore of Surtsey, Surtsey Res. Progr. Rep., 3, 46 pp., 1967.
- Jónsson, S.: Survey on the intertidal and subtidal algae on Surtsey in 1967, Surtsey Res. Progr. Rep., 4, 67–73, 1968.
- 5 Jónsson, S.: Studies of the colonization of marine benthic algae at Surtsey in 1968, Surtsey Res. Progr. Rep., 5, 42–51, 1970.
- Jónsson, S. and Gunnarsson, K.: Marine algal colonization at Surtsey, Surtsey Res. Progr. Rep., 9, 33–45, 1982.
- Kotzerka, J., Hatch, S. A., and Garthe, S.: Evidence for foraging-site fidelity and individual foraging behavior of pelagic cormorants rearing chicks in the Gulf of Alaska, Condor, 113, 80–88, 2011.
- 10 Konar, B.: Limited effects of a keystone species: trends of sea otters and kelp forests at the Semichi Islands, Alaska, Mar. Ecol.-Prog. Ser., 199, 271–280, 2000.
- Konar, B. and Estes, J. A.: The stability of boundary regions between kelp beds and deforested areas, Ecology, 84, 174–185, 2003.
- 15 Lebednik, P. A. and Palmisano, J. F.: Ecology of Marine Algae, in: The Environment of Amchitka Island, Alaska, edited by: Merritt, M. L. and Fuller, R. G., US Report NVO-79. Technical Information Center, Energy Research and Development Administration, Washington DC, 353–393, 1977.
- 20 Lindeberg, M. R. and Lindstrom, S. C.: Field Guide to Seaweeds of Alaska, Alaska Sea Grant College Program, University of Alaska Fairbanks, SG-ED-69, 188 pp., 2010.
- Merriam, C. H.: Bogoslof: our newest volcano, in: Harriman Alaska Series, Vol. II History, Geography, Resources, edited by: Dall, W. H., Keeler, C., Ferno, B. E., Gannett, H., Brewer, W. H., Merriam, C. H., Grinnell, G. B., and Washburn, M. L., Smithsonian Institution, Washington DC, Publication 1991, 291–336, 1910.
- 25 O'Clair, C. E.: Marine invertebrates in rocky intertidal communities, in: The Environment of Amchitka Island, Alaska, edited by: Merritt, M. L. and Fuller, R. G., US Report NVO-79. Technical Information Center, Energy Research and Development Administration, Washington DC, 355–449, 1977.
- 30 O'Clair, R. M. and Lindstrom, S. C.: North Pacific Seaweeds, Plant Press, Auke Bay, Alaska, 162 pp., 2000.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

- O'Connor, K. C. and Anderson, T. W.: Consequences of habitat disturbance and recovery to recruitment and the abundance of kelp forest fishes, *J. Exp. Mar. Biol. Ecol.*, 386, 1–10, 2010.
- Oliver, J. S. and Slattery, P. N.: Destruction and opportunity on the sea floor: effects of gray whale feeding, *Ecology*, 66, 1965–1975, 1985.
- Oliver, J. S., Slattery, P. N., Hulberg, L. W., and Nybakken, J. W.: Relationships between wave disturbance and zonation of benthic invertebrate communities along a subtidal high-energy beach in Monterey Bay, California, *Fish. B.-NOAA*, 78, 437–454, 1980.
- Petersen, A.: Formation of a bird community on a new island, Surtsey, Iceland, *Surtsey Res.*, 12, 133–148, 2009.
- Reisewitz, S. E., Estes, J. A., and Simenstad, C. A.: Indirect food web interactions: sea otters and kelp forest fishes in the Aleutian archipelago, *Oecologia*, 146, 623–631, 2006.
- Romagnoli, C., Mancini, F., and Brunelli, R.: Historical shoreline changes at an active volcano: Stromboli, Italy, *J. Coastal Res.*, 22, 739–749, 2006.
- Ronconi, R. A. and St. Clair, C. C.: Management options to reduce boat disturbance on foraging black guillemots (*Cephus grylle*) in the Bay of Fundy, *Biol. Conserv.*, 108, 265–271, 2002.
- Schaefer, J. R., Cameron, C. E., and Nye, C. J.: Historically Active Volcanoes of Alaska, Alaska Department of Natural Resources, Division of Geological & Geophysical Surveys, Miscellaneous Report MP 133, 1 pp., 2009.
- Scott, W. E., Nye, C. J., Waythomas, C. F., and Neal, C. A.: August 2010 eruption of Kasatochi Volcano, Aleutian Islands, Alaska – resetting an island landscape, *Arct. Antarct. Alp. Res.*, 42, 250–259, 2010.
- Siddon, E. C., Siddon, C. E., and Stekoll, M. S.: Community level effects of *Nereocystis luetkeana* in southeastern Alaska, *J. Exp. Mar. Biol. Ecol.*, 36, 8–15, 2008.
- Sigurdsson, A.: The coastal invertebrate fauna of Surtsey and Vestmannaeyjar, *Surtsey Res. Progr. Rep.*, 4, 95–107, 1968.
- Sikes, D. S. and Slowik, J.: Terrestrial arthropods of pre- and post-eruption Kasatochi Island, Alaska, 2008–2009: a shift from a plant-based to a necromass-based food web, *Arct. Antarct. Alp. Res.*, 42, 297–305, 2010.
- Stabeno, P. J., Kachel, D. G., Kachel, N. B., and Sullivan, M. E.: Observations from moorings in the Aleutian Passes: temperature, salinity and transport, *Fish. Oceanogr.*, 14, 39–54, 2005.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Talbot, S. S., Talbot, S. L., and Walker, L. R.: Post-eruption legacy effects and their implications for long-term recovery of the vegetation on Kasatochi Island, Alaska, *Arct. Antarct. Alp. Res.*, 42, 285–296, 2010.

VanBlaricom, G. R.: Experimental analyses of structural regulation in a marine sand community exposed to oceanic swell, *Ecol. Monogr.*, 52, 283–305, 1982.

Vicknair, K. E. and Estes, J.: Interactions among sea otters, sea stars, and suspension-feeding invertebrates in the western Aleutian archipelago, *Mar. Biol.*, 159, 2641–2649, 2012.

Walker, L. R., Sikes, D. S., DeGange, A. R., Jewett, S. C., Michaelson, G., Talbot, S. L., Talbot, S. S., Wang, B., and Williams, J. C.: Biological legacies: Direct early ecosystem recovery and food web reorganization after a volcanic eruption in Alaska, *Ecoscience*, 20, 240–251, 2013.

Wang, B., Michaelson, G., Ping, C.-L., Plumlee, G., and Hageman, P.: Characterization of pyroclastic deposits and pre-eruptive soils following the 2008 eruption of Kasatochi Island volcano, Alaska, *Arct. Antarct. Alp. Res.*, 42, 276–284, 2010.

Waythomas, C. F., Scott, W. E., and Nye, C. J.: The geomorphology of an Aleutian Volcano following a major eruption: the 7–8 August 2008 eruption of Kasatochi Volcano, Alaska, and its aftermath, *Arct. Antarct. Alp. Res.*, 42, 260–275, 2010a.

Waythomas, C. F., Scott, W. E., Prejean, S. G., Schneider, D. J., Izbekov, P., and Nye, C. J.: The 7–8 August 2008 eruption of Kasatochi Volcano, central Aleutian Islands, Alaska, *J. Geophys. Res.*, 115, B00B06, doi:10.1029/2010JB007437, 2010b.

Williams, J. C., Drummond, B. A., and Buxton, R. T.: Initial effects of the August 2008 volcanic eruption on breeding birds and marine mammals at Kasatochi Island, Alaska, *Arct. Antarct. Alp. Res.*, 42, 306–314, 2010.

Yu, O. H., Soh, H. Y., and Suh, H.-L.: Seasonal zonation patterns of benthic amphipods in a sandy surf zone of Korea, *J. Crustacean Biol.*, 22, 459–466, 2002.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table A1. Comparison of observations at six nearshore transects off Kasatochi Island, June and August 2009, August 2012 and June 2013 (see Fig. 2).

	12–15 Jun, 10–12 Aug 2009	28 Aug 2012	17 Jun 2013
Transect	1	1	1
Location	52°10.639' N; 175°29.510' W	52°10.639' N; 175°29.510' W	52°10.639' N; 175°29.510' W
Depth, m	20	22	22–30
Canopy kelp	absent	absent	absent
Observation method	Splashcam™ (Aug)	Splashcam™	Splashcam™
Substrate	mud/sand & few boulders	course sand, few small rocks	sand, cobble, boulders
Benthic biota	absent	diatoms & light green algae	germling brown algae < 3 cm
Transect	2	2	2
Location	52°10.141' N; 175°29.390' W	52°10.141' N; 175°29.390' W	52°10.141' N; 175°29.390' W
Depth, m	10	12	12
Canopy kelp	absent	absent ^a	absent
Observation method	diver (Jun)	Splashcam™	Splashcam™
Substrate	coarse sand/few boulders	coarse sand/few boulders	mostly boulders
Benthic biota	1 unidentified small fish; golden diatom mats interspersed with filamentous green alga, <i>Urospora</i> sp., on boulders.	Dragon kelp <i>Eualaria fistulosa</i> with some red algae	mostly germling brown algae with some <i>E. fistulosa</i> & red algae
Transect	2	2	2
Location	52°10.160' N; 175°29.180' W	52°10.160' N; 175°29.180' W	52°10.160' N; 175°29.180' W
Depth, m	20	20	20
Canopy kelp	absent	absent ^a	absent
Observation method	Splashcam™ (Aug)	Splashcam™	Splashcam™
Substrate	mud between coarse sand waves	course sand	course sand
Benthic biota	absent	1 small halibut	absent

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

Table A1. Continued.

	12–15 Jun, 10–12 Aug 2009	28 Aug 2012	17 Jun 2013
Transect	3	3	3
Location	52°9.354' N; 175°29.965' W	52°9.354' N; 175°29.965' W	52°9.354' N; 175°29.965' W
Depth, m	10	12	9
Canopy kelp	absent	absent	absent
Observation method	diver (Jun)	Splashcam™	Splashcam™
Substrate	sand	coarse sand/few pebbles	coarse sand/few pebbles
Benthic biota	absent	2 small flatfish	absent
Transect	3	3	3
Location	52°9.077' N; 175°29.717' W	52°9.077' N; 175°29.717' W	52°9.077' N; 175°29.717' W
Depth, m	14	15	17.7
Canopy kelp	absent	absent	absent
Observation method	Splashcam™ (Jun)	Splashcam™	Splashcam™
Substrate	sand/gravel/boulder	sand/gravel/boulder	coarse sand
Benthic Biota	dense young brown algae, mainly <i>E. fistulosa</i> , some <i>Cymathaere triplicata</i> , <i>Alaria marginata</i> , <i>Laminaria</i> sp., <i>Saccharina groenlandica</i> , red algae, <i>Porphyra</i> sp., on boulders; 1 yellow Irish lord	dense brown algae, <i>S. groenlandica</i> with some <i>E. fistulosa</i>	dominated by <i>S. groenlandica</i> with no visible hard substrate, evidence of partial burial, also some large <i>E. fistulosa</i>

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table A1. Continued.

	12–15 Jun, 10–12 Aug 2009	28 Aug 2012	17 Jun 2013
Transect	3	3	3
Location	52°8.930' N; 175°29.700' W	52°8.930' N; 175°29.700' W	52°8.930' N; 175°29.700' W
Depth, m	20	22	24.4
Canopy kelp	absent	absent	absent
Observation method	Splashcam™ (Aug)	not surveyed	Splashcam™
Substrate	coarse sand/few boulders		coarse sand/few small rocks
Benthic biota	young <i>E. fistulosa</i>		young <i>Saccharina groenlandica</i> , red algae, 1 yellow Irish lord
Transect	4	4	4
Location	52°10.473' N; 175°32.063' W	52°10.473' N; 175°32.063' W	52°10.473' N; 175°32.063' W
Depth, m	10	12	10
Canopy kelp	absent	present ^b	present
Observation method	diver (Aug)	Splashcam™	Splashcam™
Substrate	coarse sand and boulders	coarse sand/few boulders	boulders/coarse sand
Benthic biota	large dead barnacles on boulders; small brown algae <i>Saccharina groenlandica</i> dominated (some fertile), other browns, <i>Cymathoere triplicata</i> and <i>Desmarestia aculeata</i> , and a red, <i>Porphyra</i> sp.	<i>E. fistulosa</i> dominated	<i>E. fistulosa</i> dominated with <i>S. groenlandica</i> and <i>A. marginata</i> as understory kelp, amphipods

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table A1. Continued.

	12–15 Jun, 10–12 Aug 2009	28 Aug 2012	17 Jun 2013
Transect	4	4	4
Location	52°10.570' N; 175°32.034' W	52°10.570' N; 175°32.034' W	52°10.570' N; 175°32.034' W
Depth, m	12 (north of transect)	13 (north of transect)	17
Canopy kelp	absent	present	present
Observation method	Splashcam™ (Aug)	Splashcam™	Splashcam™
Substrate	coarse sand, sediment bubbles	coarse sand, few boulders	coarse sand, few boulders
Benthic biota	young <i>S. groenlandica</i> ; barnacles on one boulder, undetermined if alive	<i>E. fistulosa</i> dominated	young <i>S. groenlandica</i> dominated, 1 unidentified fish
Transect	4	4	4
Location	52°10.420' N; 175°32.198' W	52°10.420' N; 175°32.198' W	52°10.420' N; 175°32.198' W
Depth, m	20	21	20
Canopy kelp	absent	present	absent
Observation method	Splashcam™ (Aug)	Splashcam™	Splashcam™
Substrate	mud/fine sand, gravel pockets	coarse sand, boulders	coarse sand
Benthic biota	absent	<i>E. fistulosa</i> dominated	absent
Transect	5	5	5
Location	52°10.775' N; 175°31.649' W	52°10.775' N; 175°31.649' W	52°10.775' N; 175°31.649' W
Depth, m	10 (Tundering Cove)	15 (Tundering Cove)	15 (Tundering Cove)
Canopy kelp	absent	present	absent
Observation method	diver (Jun)	Splashcam™	Splashcam™
Substrate	coarse sand/gravel/boulders	fine sand, few boulders	coarse sand/gravel/boulders
Benthic biota	golden diatom mats, green alga, <i>Urospora</i> sp.; brown alga, <i>E. fistulosa</i> or <i>Alaria marginata</i> ; red, <i>Porphyra</i> sp.; Auklet eggs	few <i>E. fistulosa</i>	few sand dollars, <i>Echinarachnius parma</i>

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Table A1. Continued.

	12–15 Jun, 10–12 Aug 2009	28 Aug 2012	17 Jun 2013
Transect	6	6	6
Location	52°11.000' N; 175°31.342' W	52°11.000' N; 175°31.342' W	52°11.000' N; 175°31.342' W
Depth, m	10	12	12
Canopy kelp	absent	present	absent
Observation method	diver (Aug)	Splashcam™	Splashcam™
Substrate	sand/gravel/cobble/boulder	sand/gravel/cobble/boulder	sand/gravel/cobble/boulder
Benthic biota	golden diatom mats; silky red alga <i>Porphyra</i> sp., brown alga <i>S. groenlandica</i> , on one large rock; dead & live barnacles on few boulders; few juvenile flatfish ~ 1–2 cm long on sand	dominated by barnacles & <i>E. fistulosa</i> , some <i>Cymathaere triplicata</i>	dominated by small <i>E. fistulosa</i> with some <i>A. marginata</i> , <i>S. groenlandica</i> , and red algae, probably <i>Porphyra</i> sp.
Transect	6	6	6
Location	52°11.038' N; 175°31.350' W	52°11.038' N; 175°31.350' W	52°11.038' N; 175°31.350' W
Depth, m	20	22	22
Canopy kelp	absent	absent	absent
Observation method	Splashcam™ (Aug)	Splashcam™	Splashcam™
Substrate	mud	sand, few cobble & rocks	sand, few cobble & rocks
Benthic biota	absent	absent	small unidentified brown algae

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

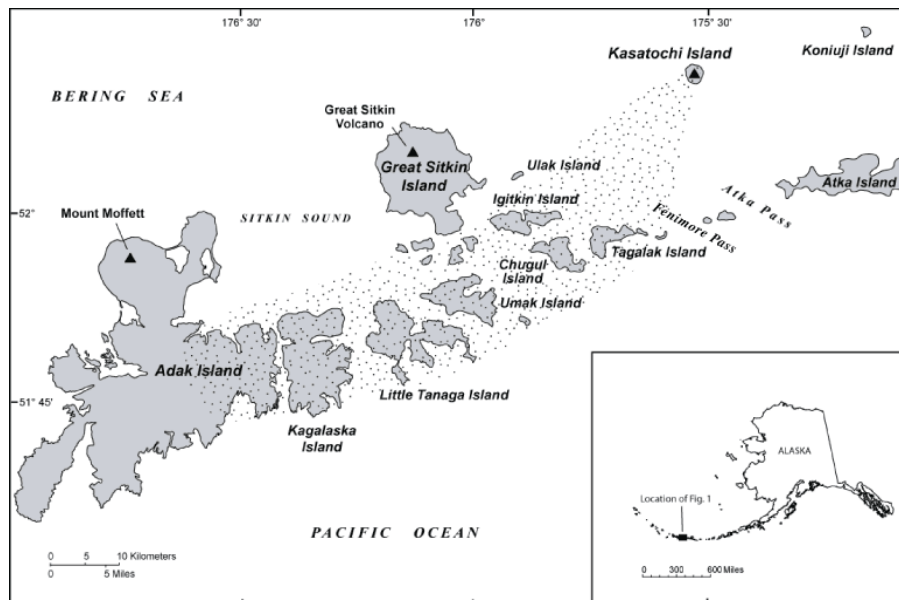


Fig. 1. Location of Kasatochi Island in the central Aleutian Islands of Alaska. Also shown are nearby islands and extent of ash fall from the 7–8 August 2008 eruption.

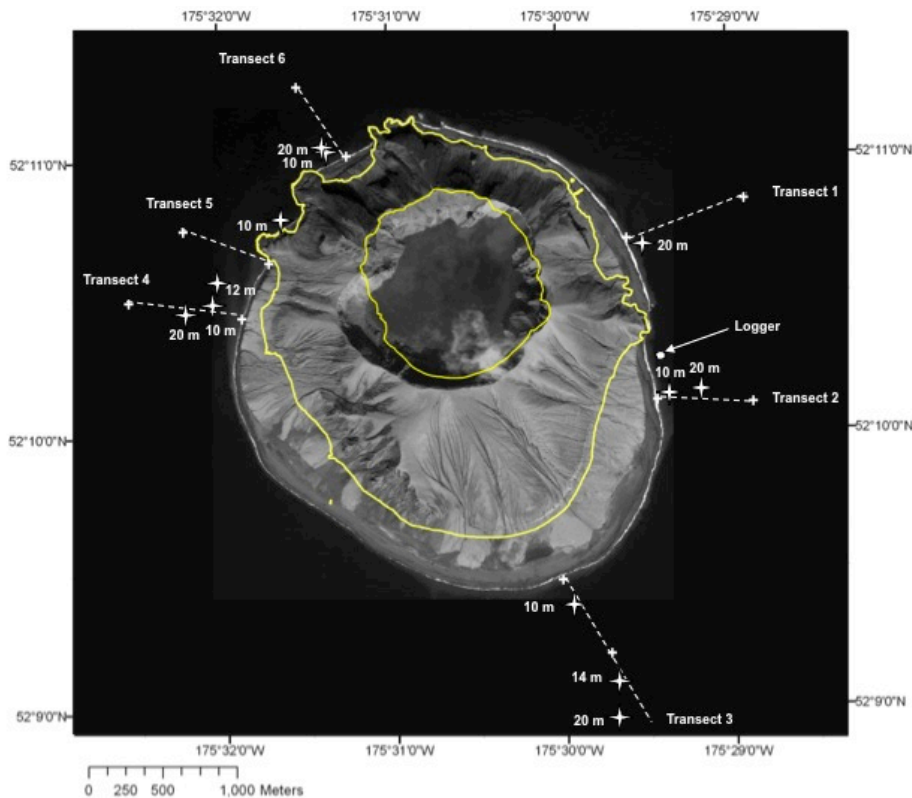


Fig. 2. Transects and locations where sampling occurred via divers at 10 m, June and August 2009, and where observations were made with a drop camera at > 10 m, June and August 2009, August 2012 and June 2013. Image was taken 18 April 2009, 9.3 months post-eruption. Yellow line is the pre-eruption shoreline based on an image taken 9 April 2004.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and G. S. Drew

Title Page	
Abstract	Introduction
Conclusions	References
Tables	Figures
◀	▶
◀	▶
Back	Close
Full Screen / Esc	
Printer-friendly Version	
Interactive Discussion	



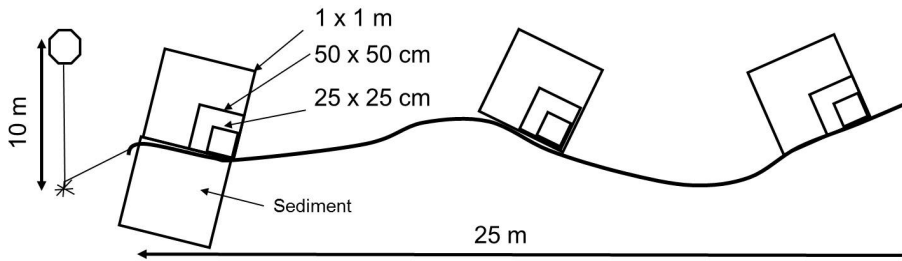


Fig. 3. Benthic sampling layout for scuba divers.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page	
Abstract	Introduction
Conclusions	References
Tables	Figures
◀	▶
◀	▶
Back	Close
Full Screen / Esc	
Printer-friendly Version	
Interactive Discussion	

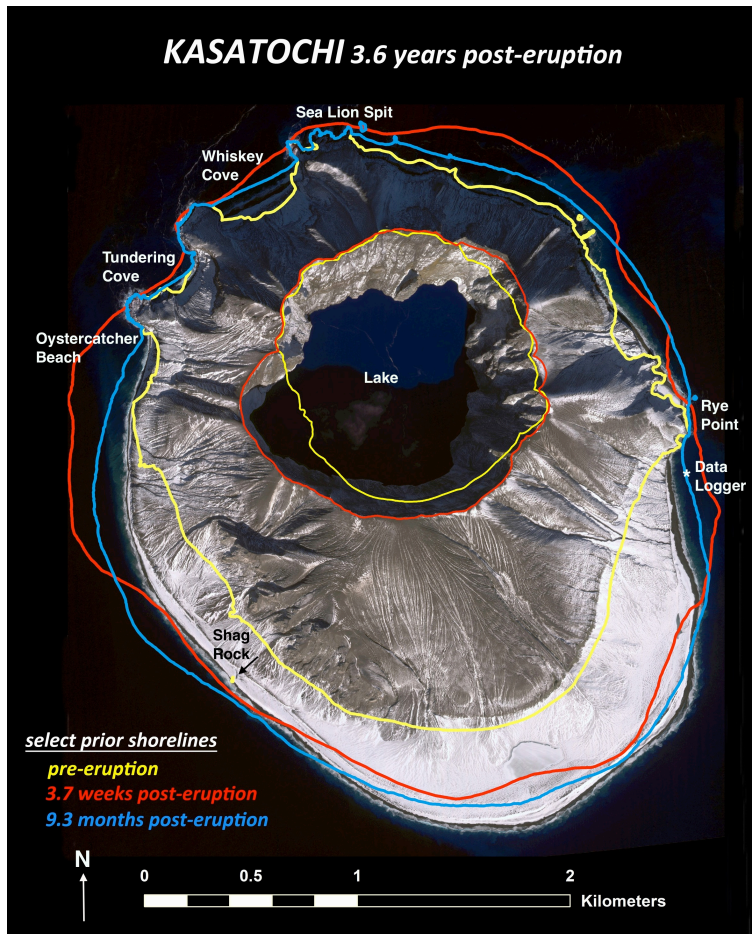


Fig. 4. Satellite image of Kasatochi Island 3.6 years following the August 2008 eruption. Shorelines of pre-eruption, 3.7 weeks and 9.3 months post-eruption are also shown.

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract Introduction

Conclusions References

Tables Figures

◀ ▶

◀ ▶

Back Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

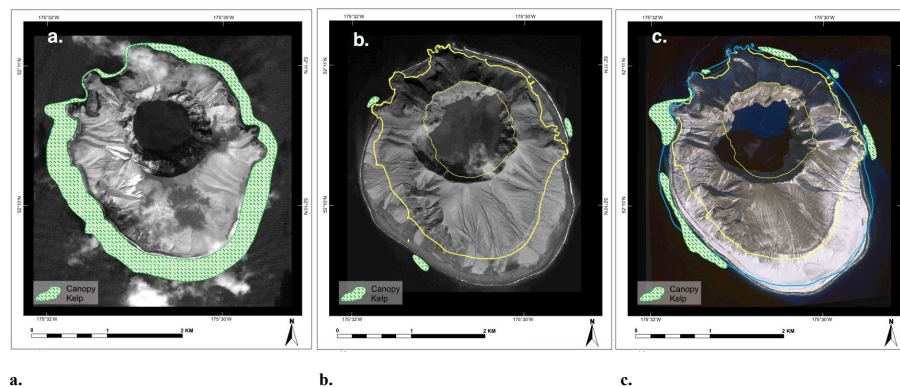


Fig. 5. Generalized distributions of canopy kelp (mainly dragon kelp *Eualaria fistulosa*) by observations around Kasatochi Island. **(a)** Pre-eruption distribution on a satellite image taken 9 April 2004. **(b)** Distribution one year (10–12 August 2009) after the eruption on a satellite image taken 18 April 2009. Yellow lines denote pre-eruption boundary of 9 April 2004. **(c)** Distribution four years (28 August 2012) after the eruption on a satellite image taken 20 February 2012. Yellow lines denote pre-eruption boundary of 9 April 2004. Blue line denotes shoreline of 18 April 2009.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

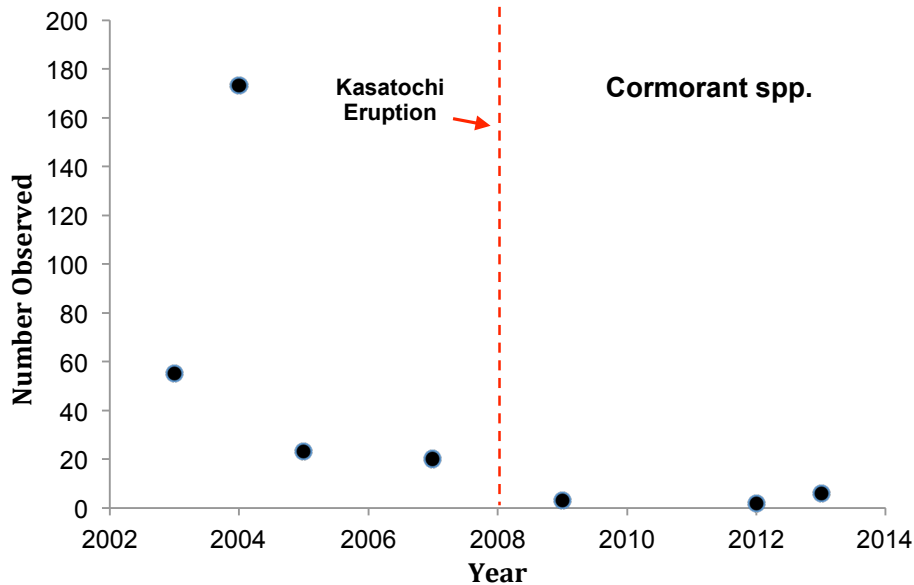


Fig. 6. Cormorant *Phalacrocorax* spp. counts from nearshore skiff censuses of Kasatochi Island. Censuses were opportunistic, though most were conducted in June.

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



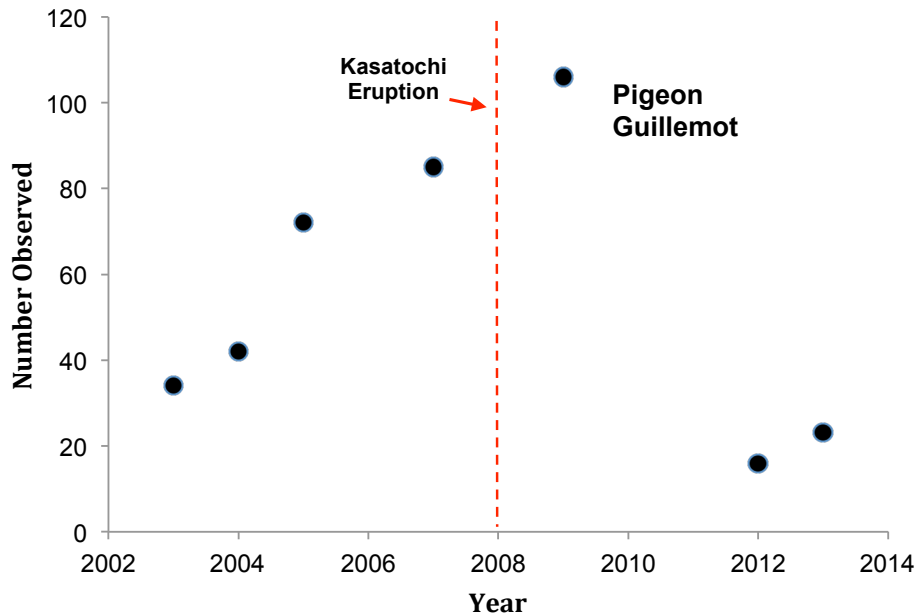


Fig. 7. Pigeon guillemot *Cephus columba* counts from nearshore skiff censuses of Kasatochi Island. Censuses were opportunistic, though most were conducted in June.

BGD

11, 3799–3836, 2014

Recolonization of the intertidal and shallow subtidal community

S. C. Jewett and
G. S. Drew

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

