

## STATUS AND TRENDS OF THE ROCKY INTERTIDAL COMMUNITY ON THE FARALLON ISLANDS

Jan Roletto<sup>1</sup>, Scott Kimura<sup>2</sup>, Natalie Cosentino-Manning<sup>3</sup>,  
Ryan Berger<sup>4</sup>, and Russell Bradley<sup>4</sup>

**ABSTRACT.**—The Farallon Islands in the Gulf of the Farallones National Marine Sanctuary (GFNMS) is a 7-island chain located 48 km west of San Francisco, California. Since 1993, GFNMS biologists and associates have monitored algal and invertebrate species abundances on the intertidal shores of the 2 South Farallon Islands. The monitoring occurred 1–3 times yearly in 6 study areas. In each study area, 3–4 permanent, 0.15-m<sup>2</sup> quadrats located between the upper and midintertidal zones were sampled for algal and sessile invertebrate cover and invertebrate counts. Taxonomic surveys were also completed to document other species in the vicinity of the sampling quadrats and to further characterize the sampling areas. Here we report monitoring results for the period 1993 to 2011. While species richness has remained relatively stable and high compared to the nearest mainland sites (Sonoma County through San Mateo County), there has been a slow, long-term net decline in the abundance of algal species and mussels at various sites on the islands. Causes for the declines remain unknown, but increased trampling from rising numbers of pinnipeds and increased waste from pinnipeds and seabirds are among the influences suspected to be important.

**RESUMEN.**—Las Islas Farallon en el Santuario Nacional Marino Golfo de Farallones (SNMGF) es un archipiélago de siete islas situado a 48 km al oeste de San Francisco, California. Desde 1993, los biólogos y asociados del SNMGF han monitoreado la abundancia de especies de algas e invertebrados en las costas intermareales de las dos Islas Farallon del sur. El seguimiento se produjo una a tres veces al año en seis áreas de estudio, en los que se estudiaron de tres a cuatro cuadrantes permanentes de 0.15 m<sup>2</sup> situados entre las zonas intermareales superior y media donde se muestrearon la cubierta de algas y el número de invertebrados sésiles. Adicionalmente, se realizaron estudios taxonómicos para documentar otras especies y caracterizar las áreas de muestreo en las proximidades de los cuadrantes. Aquí incluimos los resultados del monitoreo para el período entre 1993 y 2011. Mientras que la riqueza de especies se ha mantenido relativamente estable y elevada en comparación con otros sitios de muestreo cercanos en el continente (Condado de Sonoma a al Condado de San Mateo), se ha observado un lento descenso neto a largo plazo en la abundancia de especies de algas y mejillones en varios sitios en las islas. Las causas de este descenso siguen siendo desconocidas, pero se sospecha que la influencia del aumento en el pisoteo del creciente número de pinnípedos y el aumento de los residuos de pinnípedos y aves marinas son importantes.

The Farallon Islands in the Gulf of the Farallones National Marine Sanctuary (GFNMS) is a chain of 7 islands and emergent rocky pinnacles located 48 km (30 mi) west of San Francisco, California, 37°42' N and 123°00' W (Fig. 1). The islands and pinnacles are part of a granitic submarine ridge flanking the continental shelf (Blankinship and Keeler 1892, Hanna 1951). They are recognized as an ecosystem unique for its location and diversity of species across a broad range of biological communities. For these reasons, the habitats and natural resources at the islands and emergent pinnacles are afforded many levels of resource management, protection, conservation, and oversight. Above the mean high-tide level, the terrestrial portions of

the islands are within the Farallon National Wildlife Refuge. Below the mean high-tide level, the intertidal and subtidal areas are within GFNMS and are recognized and designated by the State Water Resources Control Board as an Area of Special Biological Significance (ASBS). Furthermore, portions of the islands' intertidal and subtidal are designated as State Marine Protected Areas (MPAs), which were created by the Marine Life Protection Act passed by the California State Legislature in 1999. At the Farallon Islands are 2 state marine reserves, 2 special closure areas, and one state marine conservation area. Also, the islands are not open to public visitation, and access is by permit and for scientific purposes only.

<sup>1</sup>Gulf of the Farallones National Marine Sanctuary, 991 Marine Dr., San Francisco, CA 94129. E-mail: jan.roletto@noaa.gov

<sup>2</sup>Tenera Environmental, 141 Suburban Rd., Suite A2, San Luis Obispo, CA 93401.

<sup>3</sup>National Oceanic and Atmospheric Administration, Fisheries Restoration Center, 777 Sonoma Ave., Santa Rosa, CA 95404.

<sup>4</sup>Point Blue (formerly PRBO) Conservation Science, 3820 Cypress Drive #11, Petaluma, CA 94954.

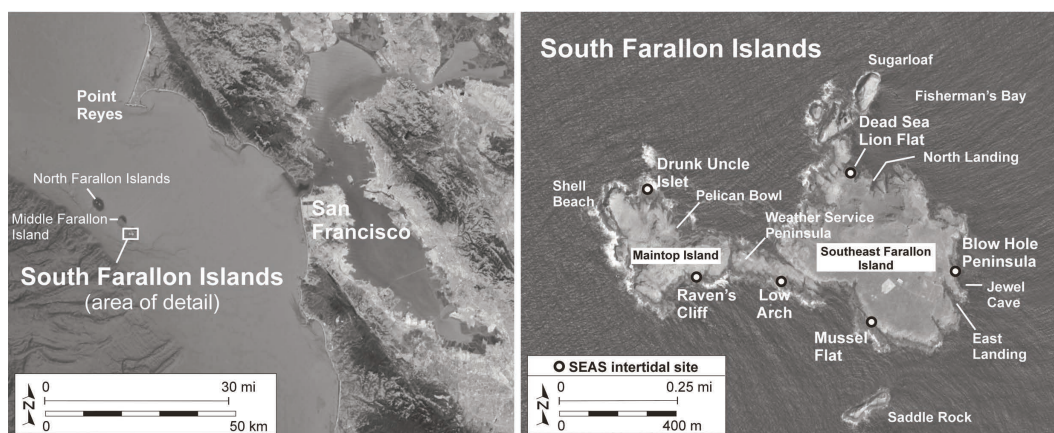


Fig. 1. Sanctuary Ecosystem Assessment Surveys (SEAS) rocky intertidal study areas on the South Farallon Islands, California ( $37^{\circ}42' N$ ,  $123^{\circ}00' W$ ). Dots indicate locations of the 6 study areas. Map data (left panel): ©2012 Google, LDEO-Columbia, NSF, NOAA, SIO, NOAA, U.S. Navy, NGA, GEBCO, MBARI, Image Landsat. Map data (right panel): ©2008 Google, SIO, NOAA, U.S. Navy, NGA, GEBCO, CSUMB SFML, CA OPC.

Blankinship and Keeler (1892) completed the first survey of the intertidal community on the Farallon Islands. Their work provided a general description of the island's geology and biota and a temporal snapshot of the intertidal community. The next intertidal survey was 87 years later, completed by the California State Water Resources Control Board as a reconnaissance survey to consider designation of the islands as an ASBS (CSWRCB 1979). The only other published investigations involving assessment or documentation of the intertidal habitat on the islands focused on the distribution of Foraminifera (Grivetti 1962) and the systematics of Porifera (Klontz 1989).

Since 1993 and as part of the Sanctuary Ecosystem Assessment Surveys (SEAS), the GFNMS has monitored intertidal algal and invertebrate species abundances on the rocky shores of the 2 South Farallon Islands (Southeast Farallon and Maintop Islands). The long-term monitoring program was created to characterize the intertidal habitat and to maintain an ongoing database of species abundances in the event of oil spills. Here we present data spanning August 1993–February 2011 summarizing macroalgal and invertebrate changes on the Farallon Islands.

## METHODS

### Study Areas

There are 6 study areas on the 2 South Farallon Islands (Southeast Farallon and Maintop

Islands), which are the 2 largest of the 7 islands (Fig. 1). Together these islands are 44 ha in size and are separated by a narrow surge channel. A narrow and discontinuous reef characterizes the intertidal zone, exposed only on minus tides. The landward rise is often steep, highly worn, and characterized by cracks and crevices, surge channels, and sea caves (Hanna 1951). No rocks or boulder fields are found in the upper intertidal, and the only sand is coarse grained, with cobbles deposited at the heads of surge channels. Intertidal zones were categorized based on species composition. Many locations on the islands are used as seasonal and year-round haul-outs for pinnipeds. As such, the study areas selected were accessible and disturbance to pinnipeds (and seabirds) was minimized, as required by the Sanctuary and Refuge permits. The number of study areas and number of quadrats in each study area were also selected based on logistics and funding. See Appendix 1 for the physical descriptions of each study area and quadrat.

### Sampling Design

Three to four permanent,  $30 \times 50$ -cm quadrats ( $0.15 \text{ m}^2$ ) between the upper and midintertidal zones (Ricketts et al. 1985) were sampled in each of the 6 study areas (Fig. 1). The quadrat locations were marked with marine epoxy on the rock substrate. Sampling was completed up to 3 times annually (August,

November, February), beginning in 1993. Sampling was not scheduled to occur during the peak algal growth season (May–July) to minimize and avoid disturbance to breeding seabirds and pinnipeds that typically use the sampling areas.

All surveys included taking photographs of each quadrat followed by point-intercept sampling, which consisted of sampling 50 random points for algal and sessile invertebrate cover. All algal and sessile invertebrate species under each sampling point were identified and recorded to the lowest taxonomic level practical (Foster et al. 1991, Dethier et al. 1993). Multiple layers of the same species (taxon) at a single sampling point were tallied as a single occurrence, but layers of multiple species under a single point resulted in multiple tallies (contacts) per sampling point. As such, total algal cover (all species tallies combined for a quadrat) could exceed 100% cover for highly layered quadrats. Point-intercept assessments in each quadrat also included a tally of dead animals (i.e., empty barnacle tests or shells and percentage of dead or bleached algae/plants) and the number of contacts of bare (uncolonized) rock or sand and crustose species across the sampling points.

Invertebrate densities within each quadrat were based on counts of select species (taxa) within 25 × 25-cm and 10 × 10-cm subquadrats, nested within the 30 × 50-cm quadrats. Data are presented here only for *Mytilus californianus*, due to low occurrences of other invertebrates.

Algal and invertebrate species of uncertain identity were collected from outside the quadrat and identified in the laboratory. Identifications were based primarily on Dawson and Foster (1966), Kozloff (1983), Smith and Carlton (1975), Abbott and Hollenberg (1976), and Carlton 2007. Algal voucher specimens are presently archived at the GFNMS office in San Francisco, California, and at the University of California, Berkeley, Jepson Herbarium.

## RESULTS

For the period February 1993–February 2011, the rocky intertidal species inventory for the South Farallon Islands consisted of 223 invertebrate taxa, 7 fish taxa, 187 algal taxa, and 1 seagrass taxon (Appendixes 2–4). Of all the algal species listed in Appendix 4,

three are presently considered to be rare in the sampling region or outside their normal range: *Branchioglossum undulatum* and *Myriogramme variegata* have not been previously documented north of Carmel Bay, California, and *Ulva conglobata* is considered an introduced species.

Species abundances, averaged across all 6 study areas for 2010 and 2011 (the most recent sampling years), revealed that the top 10 species comprised >90% of the total upright algal cover for those 2 years combined. Species abundance was variable across the 6 study areas, except for the articulated coralline algal species *Corallina vancouveriensis*, which was either the first or second most abundant species (>20% mean cover) in the study areas (Table 1). The *Mazzaella flaccida*-complex, a foliose red algal assemblage, was also abundant, except in the quadrats at Mussel Flat, where *Anthopleura elegantissima* covered large amounts of the substrate. The *Mazzaella flaccida*-complex consisted of several species of *Mazzaella*, with *M. flaccida* being the most abundant. The green sea lettuce *Ulva* spp., the branched turf alga *Gelidium* spp., the red bladed alga *Mastocarpus papillatus*, and nail brush seaweed *Endocladia muricata* were consistently found at each of the study areas, but abundance was variable, typically <20% mean cover in each area. The most commonly sampled invertebrates included mussels *Mytilus californianus*, aggregating anemones *Anthopleura elegantissima*, and the barnacles *Tetraclita rubescens* and *Balanus* spp.

From 1993 through 2011, upright (noncrustose) algal species declined in abundance (Fig. 2). Total upright algal abundance at Low Arch, for example, declined from nearly 240% mean cover to approximately 140% mean cover. At all study areas, the decline was offset by increases in crustose algal cover, which was greatest at Dead Sea Lion Flat where the combined coverage of crustose species increased from <10% mean cover to >50% mean cover from 1993 to 2011 (Fig. 3). The decline in algal cover is also substantiated by a corresponding increase in uncolonized (bare rock or sand) substrate in all areas (Fig. 4). While an overall decline in the combined coverage of upright algal species was detected, the average number of species sampled in each quadrat (i.e., species richness) over the long term has not exhibited the same trend,

TABLE 1. Mean percent cover of taxa sampled in permanent point-intercept quadrats on the South Farallon Islands, 2010–2011.

Species	Southeast Farallon Island				Maintop Island	
	Blow Hole Peninsula	Dead Sea Lion Flat	Mussel Flat	Low Arch	Drunk Uncle Islet	Raven's Cliff
<i>Bossiella/Calliarthron</i> spp.	1.3	0.5	0	0.3	0	10
<i>Corallina vancouveriensis</i>	20.8	21.5	17.3	58.7	27.3	48.8
<i>Cryptopleura/Hymenena</i> spp.	1	0	0	4	0	1.5
<i>Egrecia menziesii</i>	8	0	0	0	0	0
<i>Endocladia muricata</i>	16.5	0	4.3	0	1	0.8
filamentous green algae	0	0	7.8	0.3	0	0
filamentous red algae	0	0	10	0	0	0
<i>Gelidium</i> spp.	1	1	4.5	0.3	7	1
<i>Mastocarpus jardinii</i>	0	0	0.3	5.7	0.3	0
<i>Mastocarpus papillatus</i>	3.8	4	3	6	2.3	7.8
<i>Mazzaella affinis</i>	0.8	0.3	3.8	0.3	0	0
<i>Mazzaella flaccida</i> -complex	34	23.8	0.3	41.3	1.3	15
<i>Microcladia borealis</i>	0	0.3	0.5	0	0.3	3
<i>Microcladia coulteri</i>	0	0	0.3	0	0	0
<i>Neogastroclonium subarticulatum</i>	4.5	0.3	0.5	0	0	0
<i>Neorhodomela larix</i>	0	8.8	0	0	0	0
<i>Osmundea spectabilis</i>	0	0	0	0	0	0.3
<i>Phyllospadix scouleri</i>	0	3	0	0	0	7.3
<i>Plocanium</i> spp.	0	0	0.8	0	0	0
<i>Porphyra</i> spp.	0	0	0	0	0	1.8
<i>Prionitis</i> spp.	0	0.8	0	3	2.7	5.5
<i>Ulva</i> spp.	4.5	16.8	6	0	0	1.3
Mean number of noncrustose species	9.6	9.5	10.5	8	6.5	12
Crustose coralline complex	4.5	8.5	9.8	16.7	1.3	9.8
Crustose noncoralline complex	6.3	37.3	14	3.7	12.3	4
Bare rock/sand % cover	34.5	20	31	42.7	30	29.5
Barnacles % cover	0.5	0	5.8	4	11.3	3.3
Mussels % cover	45.3	0	0	0.3	35.3	23
Anemones % cover	0	0	25.3	0	0	0
Mean number of dead invertebrates	0.3	0.1	1.8	0.2	2.2	12
Bleached plants % cover	0.3	2.8	3.8	1.3	1.7	10.3

although taxon numbers have been variable within and between years (Fig. 5).

As with the upright algal species, *Mytilus californianus* declined at all locations that had sufficient numbers of *M. californianus* to quantify (Figs. 6, 7). Mussel cover at Blow Hole Peninsula declined from approximately 75% mean cover to approximately 45% mean cover; and at Low Arch, mussel cover declined to nearly zero abundance. The decline in mussel cover corresponded to similar declines in mussel densities (Fig. 7). For example, mussel densities at Blow Hole Peninsula declined from approximately 180 mussels  $\cdot$  0.15 m<sup>-2</sup> to approximately 135 mussels  $\cdot$  0.15 m<sup>-2</sup> and at Drunk Uncle Islet densities declined from approximately 92 mussels  $\cdot$  0.15 m<sup>-2</sup> to 33 mussels  $\cdot$  0.15 m<sup>-2</sup> (Fig. 7). In areas where mussels were less common, such as Low Arch, mussels became almost absent in 2011.

## DISCUSSION

There was a conspicuous absence of rockweeds (Fucales) on the islands. In particular, *Fucus distichus* and *Silvetia compressa* (previously *Pelvetia fastigiata*) were not found in 18 years of sampling. Prior to the beginning of the SEAS monitoring program in 1993, these 2 rockweed species were noted on the islands by Blankinship and Keeler (1892) and CSWRBCB (1979). It is not known if these records constituted an error in reporting by the investigators or if both species were actually present. The only rockweed species observed since then has been *Fucus distichus* occurring only as floating, detached drift near the islands (Cosentino et al. 2001). In contrast, rockweed species have been and continue to be very common and abundant on mainland shores in Central and Northern California (Cosentino et al. 2001, Tenera, Inc. 2011).

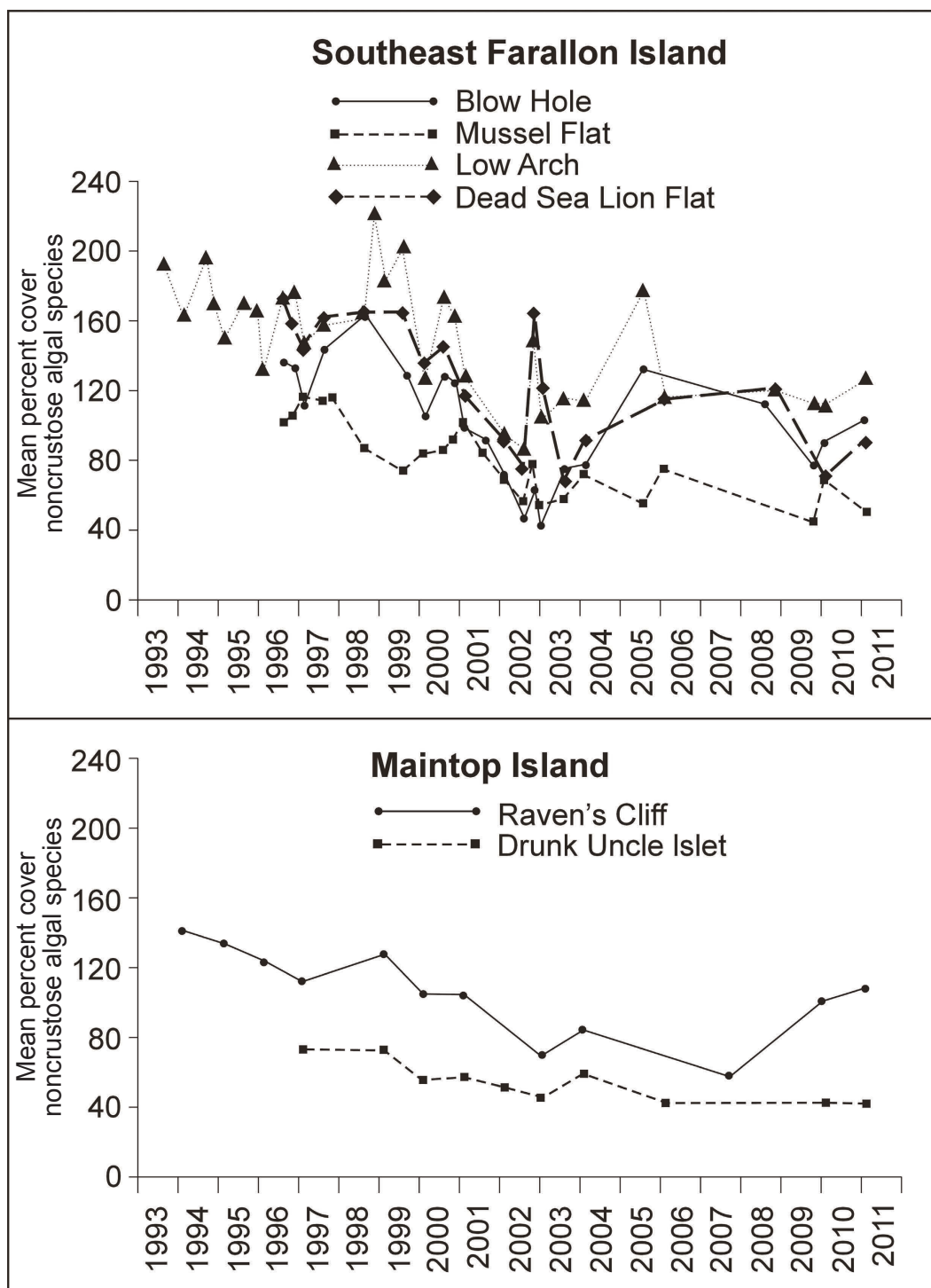


Fig. 2. Change in percent cover of all upright, noncrustose algal species at the SEAS study areas on the South Farallon Islands, 1993–2011.

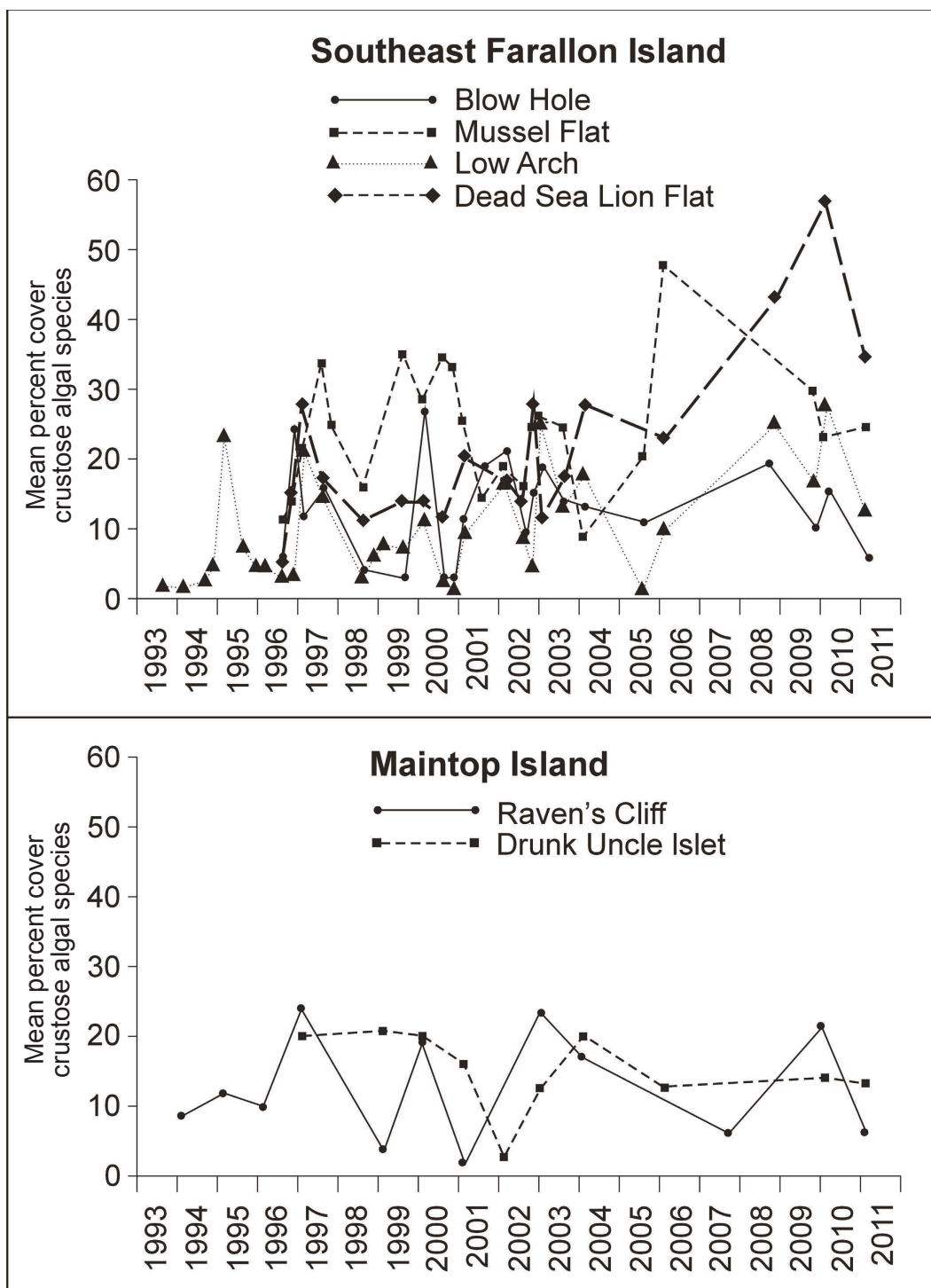


Fig. 3. Change in percent cover of all crustose algal species at the SEAS study areas on the South Farallon Islands, 1993–2011.

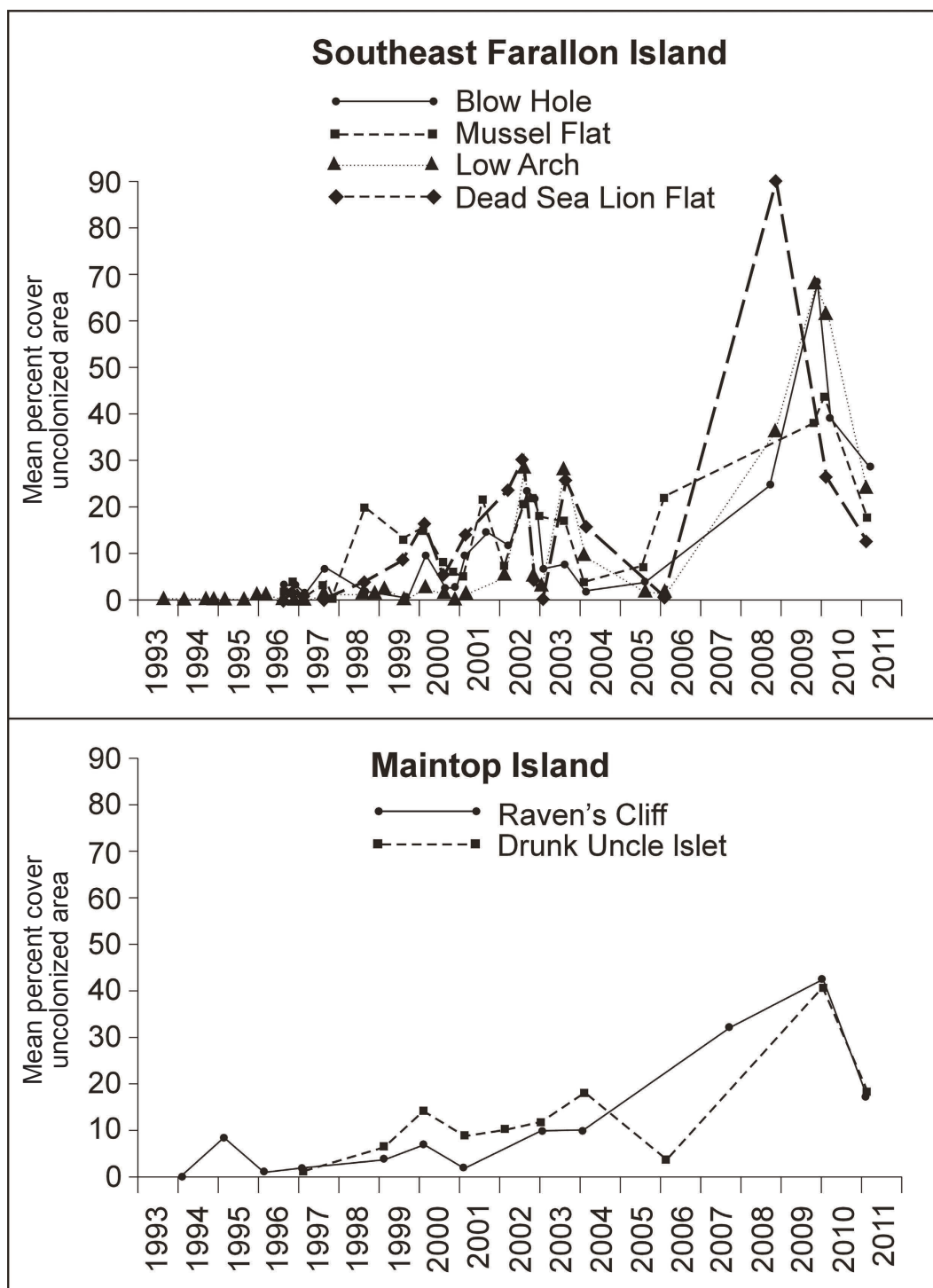


Fig. 4. Change in percent cover of uncolonized area (bare rock and sand) at the SEAS study areas on the South Farallon Islands, 1993–2011.

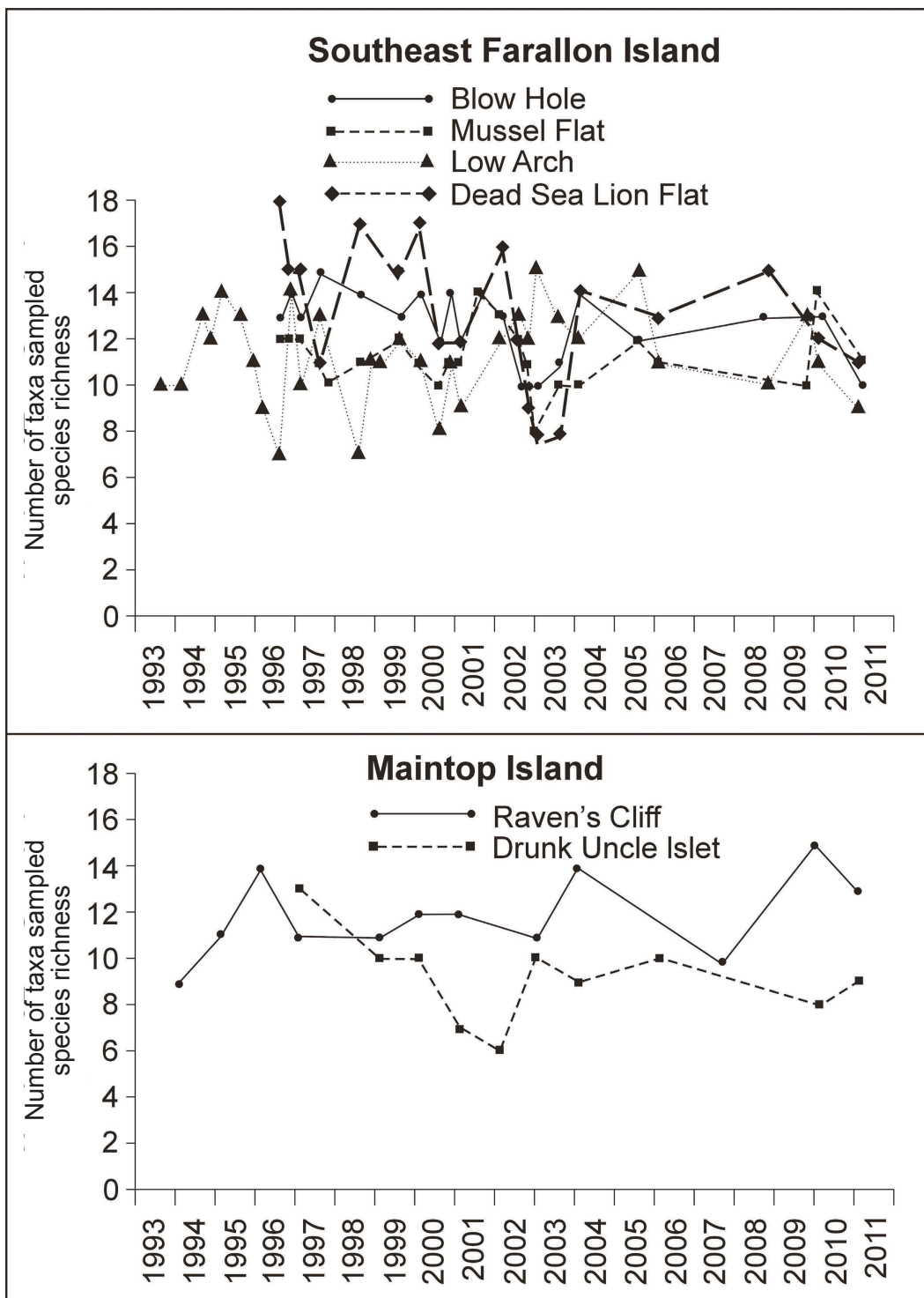


Fig. 5. Change in species richness (total taxa sampled) at the SEAS study areas on the South Farallon Islands, 1993–2011.



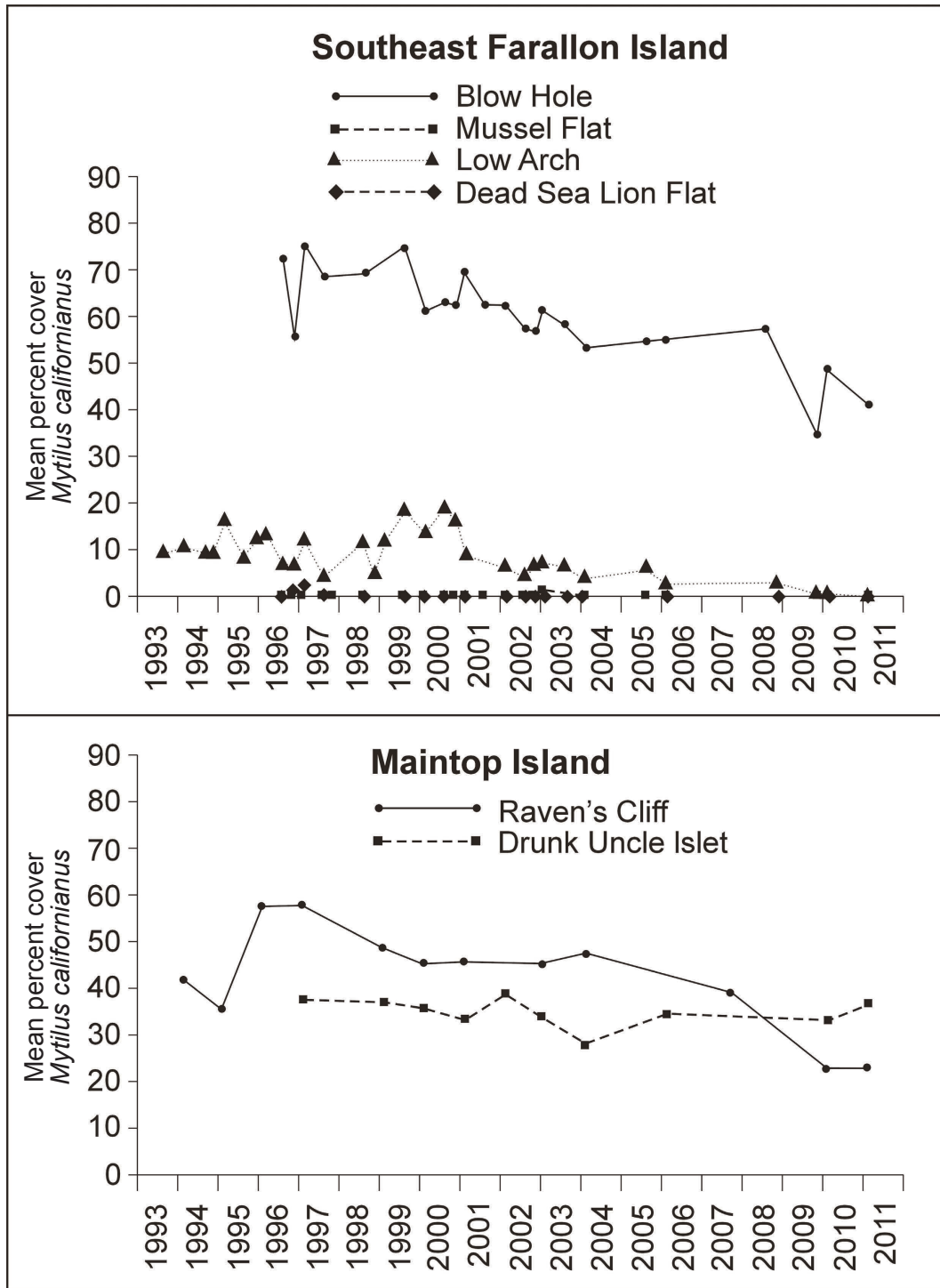


Fig. 6. Change in percent cover of *Mytilus californianus* at the SEAS study areas on the South Farallon Islands, 1993–2011.

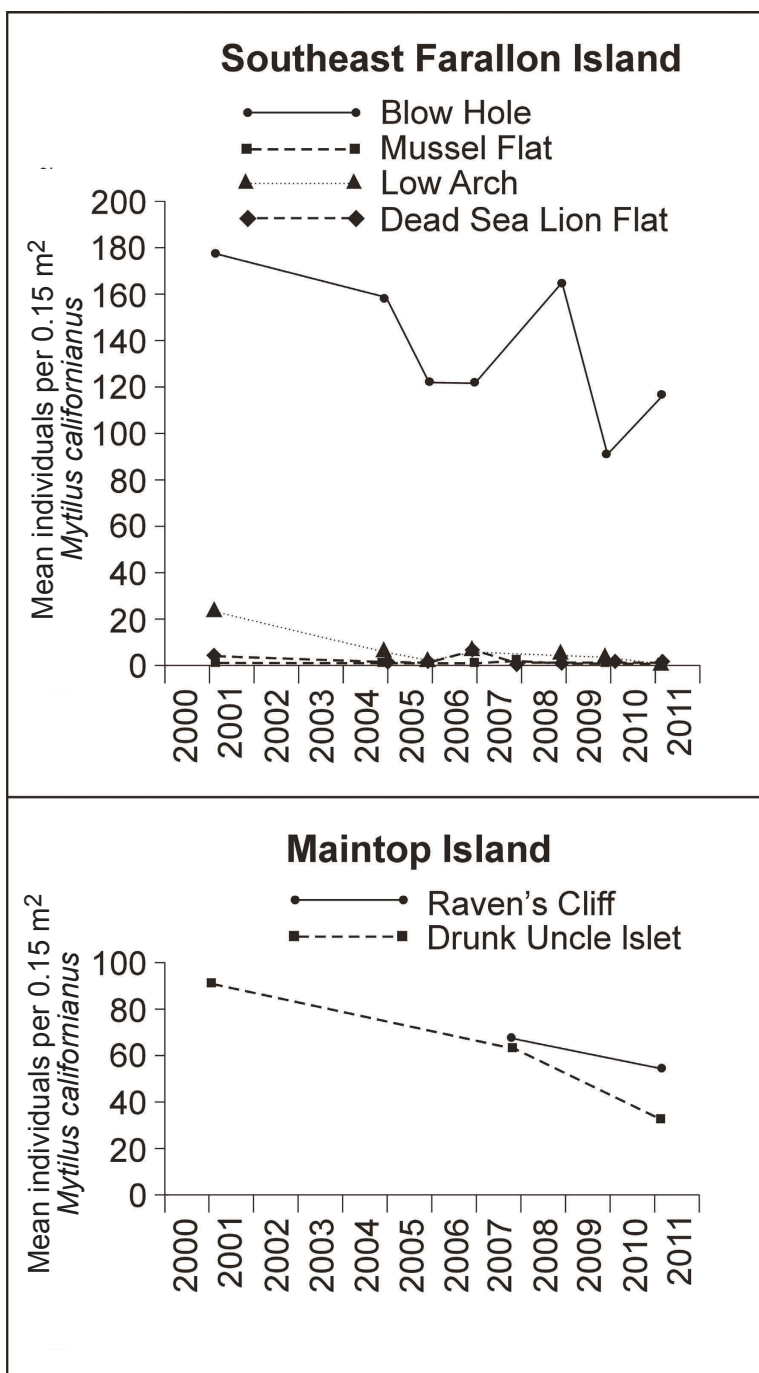


Fig. 7. Change in density of *Mytilus californianus* at the SEAS study areas on the South Farallon Islands, 2000–2011.

The data reported here for the 18-year period (1993–2011) on the South Farallon Islands reveal a slow, long-term decline in overall algal and mussel abundance and a corresponding

increase in bare substrate cover and crustose algal cover. However, short-term changes within this time span do not necessarily reflect the same shift but instead reveal much within

and between year variation (increases and decreases) among study areas. This variation can be associated with sampling error and observer variation. Different sets of biologists sampled the quadrats among the various surveys, and this may account for a portion of the data variation within and between years and among study areas. However, the overall decrease in total noncrustose algal cover and mussel abundance from 1993 to 2011 exceeds the short-term interannual variations in the data potentially associated with observer variation. This pattern provides evidence in support of the long-term changes detected and underscores the importance of conducting studies over long periods of time (i.e., decades) to ensure that changes detected in abundances are not artifacts of sampling errors related to observer variation.

The causes for the long-term declines in algal cover and mussel abundance remain unknown. Sea surface temperatures (SST) are known to influence the composition and abundance of intertidal species, spore and larval distribution, grazing, predation, and vulnerability to disease (Sagarin et al. 1999, Steinbeck et al. 2005, Petes et al. 2008). Of note, there was a large temperature increase in the present study period associated with the 1997–1998 El Niño followed by declines in temperature regimes. However, upwelling strength (inferred productivity) did not necessarily increase with the overall decrease in water temperatures (Abraham and Sydeman 2004, PFEL 2013). As such, the relationship between declines in algal and mussel abundance and shifts in water temperature regimes and nutrient associations remain unresolved. Because public access is prohibited on the South Farallon Islands, resource extraction and trampling from humans are discounted as causes for the declines. On the other hand, the declines are coincidental with (1) increased numbers of pinnepeds (Point Blue 2012) hauling out on intertidal areas to rest, breed, nurse, and molt and (2) a large increase in overall seabird numbers on the islands (Warzybok et al. 2012). Accordingly, the declines may be due in part to a trampling effect from pinnepeds, similar to what occurs from human activity on rocky shores (Boal 1980). The changes may also be influenced by increased nutrient and uric acid loading from pinniped and seabird wastes.

The declines of mussels and algae detected in the monitoring on the South Farallon Islands appear unique, as declines of similar nature have not been reported for nearby sites along the mainland coast (MARINe 2013). As such, further investigations of the relationship between the declines and rising pinniped and seabird populations, and possible climate change (e.g., sea surface temperatures, upwelling, Pacific Decadal Oscillation) are warranted to help establish cause-and-effect relationships between the intertidal biota on the Farallon Islands and factors influencing changes to the intertidal community. Further investigations are warranted to determine if the changes to the intertidal community on the islands relative to the mainland communities represent a unique set of species' responses to an atypical set of environmental influences at the islands.

#### ACKNOWLEDGMENTS

We thank Gregor Cailliet, Judith Connor, Robert Lea, and John Tarpley for their guidance, comments, and assistance in the development of this project. Field assistance was provided by Candice Brown, Maria Brown, Tony Chess, Gery Cox, Kathleen Dickey, Ellen Gartside, Charleen Gavette, Leslie Grella, Daphne Hatch, Dan Howard, Brain Jarvis, Rebecca Johnson, Amber Mace, Steven Morgan, Gillian O'Doherty, David Osorio, Carol Preston, Tim Reed, Mary Jane Schramm, Emily Siegel, Jordan Stout, Sage Tezak, Brigit Ueber, Ed Ueber, Jennifer Vick, Amity Wood, and Angie Wulfow, and by data-entry interns Cheryl Chen and Michael Falzone. Tony Chess, Gery Cox, Ellen Gartside, Dan Howard, and Rebecca Johnson made invertebrate identifications. Katie McGortey and Robert Lea made fish identifications. We gratefully acknowledge the help and consultation of Drs. Kathy Anne Miller, Tom De Cew, and Paul Silva, University of California. Logistical support came from Point Blue (formerly PRBO) Conservation Science staff Derek Lee, Elizabeth McLaren, Jerry Nussbaum, Peter Pyle, Bill Sydeman, and Jim Tietz; and from U.S. Fish and Wildlife Service, Farallon National Wildlife Refuge staff Joelle Buffa, Gerry McChesney, Michael Parker, and Jean Takekawa. The United States Coast Guard, Oceanic Society Expeditions, Farallon Island Patrol, and Mick Menigoz of

the *New Superfish* provided transportation to the island. Jaime Jahncke of Point Blue Conservation Science provided the Spanish translation of the abstract, and John Steinbeck provided a critical review of the manuscript. This work was authorized under the following permits: GFNMS-03-92, GFNMS-2011-004, and Special Use Permit #76587, Farallones National Wildlife Refuge, USFWS. This is Point Blue Conservation Science scientific contribution #1956.

## LITERATURE CITED

- ABBOTT, I.A., AND G.J. HOLLENBERG. 1976. Marine algae of California. Stanford University Press, Stanford, CA.
- ABRAHAM, C.L., AND W.J. SYDEMAN. 2004. Ocean climate, euphausiids and auklet nesting: inter-annual trends and variation in phenology, diet and growth of a planktivorous seabird, *Ptychoramphus aleuticus*. Marine Ecology Progress Series 274:235–250.
- BLANKINSHIP, J.W., AND C.A. KEELER. 1892. On the natural history of the Farallon Islands. *Zoe* 3:144–186.
- BOAL, J. 1980. Pacific harbor seal (*Phoca vitulina richardii*). Haul out impact on the rocky midtidal zone. Marine Ecology Progress Series 2:265–269.
- [CSWRCB] CALIFORNIA STATE WATER RESOURCES CONTROL BOARD. 1979. California marine waters areas of special biological significance reconnaissance survey report: Farallon Island. Water Quality Monitoring Report No. 79–13, Sacramento, CA.
- CARLTON, J.T., EDITOR. 2007. The Light and Smith manual: intertidal invertebrates from central California to Oregon. 4th edition. University of California Press, Berkeley, CA.
- COSENTINO, N., J. ROLETTA, D.A. OSORIO, AND E. UEBER. 2001. Rocky intertidal communities at the Farallon Islands, California. Status report, 2000. National Oceanic and Atmospheric Administration, Gulf of the Farallones National Marine Sanctuary, San Francisco, CA.
- DAWSON, E.Y., AND M.S. FOSTER. 1966. Seashore plants of California. University of California Press, Berkeley, CA.
- DETHIER, M.N., E.S. GRAHAM, S. COHEN, AND L.M. TEAR. 1993. Visual versus random-point percent cover estimations: “objective” is not always better. Marine Ecology Progress Series 96:93–100.
- FOSTER, M.S., C. HARROLD, AND D.D. HARDIN. 1991. Point vs. photo quadrat estimates of the cover of sessile marine organisms. *Journal of Experimental Marine Biology and Ecology* 146:193–203.
- GRIVETTI, L.E. 1962. Recent intertidal foraminifera of the Farallon Islands. Master’s thesis, University of California, Berkeley, CA.
- HANNA, G.D. 1951. Geology of the Farallon Islands. California Division Mines Bulletin 154:301–310.
- KLONTZ, S.W. 1989. Ecology and systematics of the intertidal sponges of Southeast Farallon Island. Master’s thesis, San Francisco State University, San Francisco, CA.
- KOZLOFF, E.N. 1983. Seashore life of the Northern Pacific Coast. University of Washington Press, Seattle, WA.
- MARINe. 2013. Multi-agency Rocky Intertidal Network. Available from: <http://www.pacificrockyintertidal.org>
- PFEL. 2013. Homepage [online]. Pacific Fisheries Environmental Laboratory, National Marine Fisheries Service, Pacific Grove, CA. Available from: <http://www.pfeg.noaa.gov>
- PETES, L.E., M.E. MOUCHKA, R.H. MILSTON-CLEMENTS, T.S. MOMODA, AND B.A. MENGE. 2008. Effects of environmental stress on intertidal mussels and their sea star predators. *Oecologia* 156:671–680.
- POINT BLUE. 2012. Point Blue Conservation Science (formerly PRBO). Unpublished data. Petaluma, CA.
- RICKETTS, E., J. CALVIN, AND J. HEDGEPEETH. 1985. Between Pacific Tides. 5th edition, revised by D.W. Phillips. Stanford University Press, Stanford, CA.
- SAGARIN, R.D., J.P. BARRY, S.E. GILMAN, AND C.H. BAXTER. 1999. Climate-related change in an intertidal community over short and long time scales. *Ecological Monographs* 69:465–490.
- STEINBECK, J.R., D.R. SCHIEL, AND M.S. FOSTER. 2005. Detecting long-term change in complex communities: a case study from the rocky intertidal zone. *Ecological Applications* 15:1813–1832.
- SMITH, R.I., AND J.T. CARLTON, EDITORS. 1975. Light’s manual: intertidal invertebrates of the Central California Coast. 3rd edition. University of California Press, Berkeley, CA.
- TENERA, INC. 2011. S/S *Cape Mohican* restoration project, baseline study and resource stewardship assessment report. Unpublished report to Gulf of the Farallones National Marine Sanctuary, San Francisco, CA. Available from: <http://www.marine.gov/Research/Species.html>
- WARZYBOK, P.M., R.W. BERGER, AND R.W. BRADLEY. 2012. Population size and reproductive performance of seabirds on Southeast Farallon Island, 2012. Unpublished report to the U.S. Fish and Wildlife Service. PRBO Conservation Science, Petaluma, CA.

Received 7 April 2013

Accepted 23 May 2014

Early online 15 December 2014

Appendix 1 on page 272.

Appendix 2 on page 272.

Appendix 3 on page 274.

Appendix 4 on page 274.

APPENDIX 1.—Quadrat descriptions. See Fig. 1 for exposure of wave direction at each sample area.

Quadrat number	Area	Zone	Exposure	Height above zero mean tide (m)	Used as pinniped haul-out
Q1	Blow Hole Peninsula	Mid	Semiexposed	1.6	rare
Q2	Blow Hole Peninsula	Mid	Semiexposed	2.1	rare
Q3	Blow Hole Peninsula	Mid	Exposed	2	rare
Q101	Blow Hole Peninsula	High	Semiexposed	1.8	rare
Q4	Dead Sea Lion Flat	Mid	Semiexposed	1.4	yes
Q5	Dead Sea Lion Flat	Mid	Semiexposed	1.3	yes
Q6	Dead Sea Lion Flat	High	Semiexposed	1.7	yes
Q103 <sup>a</sup>	Dead Sea Lion Flat	Low	Semiexposed	0.8	yes
Q7	Drunk Uncle Islet	Low	Semiexposed	0.7	yes
Q9	Drunk Uncle Islet	Low	Exposed	0.7	yes
Q104	Drunk Uncle Islet	High	Semiexposed	2.1	yes
Q105	Drunk Uncle Islet	Mid	Semiexposed	1.5	yes
Q10	Raven's Cliff	Mid	Exposed	1.7	yes
Q11	Raven's Cliff	Low	Semiexposed	0.4	yes
Q12	Raven's Cliff	Low	Semiexposed	0.7	yes
Q13	Raven's Cliff	High	Exposed	3.3	yes
Q14	Raven's Cliff	Mid	Semiexposed	1.7	yes
Q15	Raven's Cliff	Mid	Semiexposed	1.2	yes
Q16	Low Arch	Mid	Semiexposed	1.5	yes
Q17	Low Arch	Mid	Semiexposed	1.5	yes
Q18	Low Arch	High	Semiexposed	1.8	yes
Q19 <sup>b</sup>	Mussel Flat	Mid	Protected	0.3	no
Q20 <sup>b</sup>	Mussel Flat	Mid	Protected	0.4	no
Q22 <sup>b</sup>	Mussel Flat	Low	Protected	0.5	no
Q102 <sup>b</sup>	Mussel Flat	High	Protected	2	no

<sup>a</sup>Quadrat 103 is the only quadrat with a sandy substrate.<sup>b</sup>Quadrats 19, 20, 22, and 102 are on steeply sloping or vertical walls and are not subjected to trampling from pinnipeds.

APPENDIX 2. South Farallon Islands intertidal invertebrate species inventory, as of February 2011.

APPENDIX 2. Continued.

## ANNELIDA

*Arabella iricolor*  
*Dodecaceria fewkesi*  
*Nereis guberi*  
*Phragmatopoma californica*  
*Phyllochaetopterus prolifica*  
*Serpula vermicularis*  
*Spirorbis borealis*  
*Thelepus crispus*

## ARTHROPODA

*Acanthomysis* sp.  
*Achelia chelata*  
*Achelia nudiscula*  
*Achelia spinoseta*  
*Allorchestes anceps*  
*Alpheus dentipes*  
*Ammothea hilgendorfi*  
*Amphiodia occidentalis*  
*Anatanais normani*  
*Balanus amphitrite*  
*Balanus glandula*  
*Balanus nubilus*  
*Cancer productus*  
*Caprella anomala*  
*Caprella californica*  
*Chthamalus dalli*  
*Cirolana harfordi*  
*Elasmopus serricatus*  
*Exosphaeroma inornata*

*Fabia subquadrata*  
*Gnorimosphaeroma* sp.  
*Hemigrapsus nudus*  
*Hyale grandicornis*  
*Ianiropsis kincaidi*  
*Idotea fewkesi*  
*Idotea resecata*  
*Idotea schmitti*  
*Idotea stenops*  
*Idotea urotoma*  
*Idotea wosnesenskii*  
*Lecythorichus hilgendorfi*  
*Ligia occidentalis*  
*Ligia pallasii*  
*Limnoria algarum*  
*Littorophiloscia richardsonae*  
*Lophopanopeus leucomanus*  
*Melita californica*  
*Metacarcinus magister*  
*Nymphopsis spinosissima*  
*Oedignathus inermis*  
*Oligochinus lighti*  
*Pachygrapsus crassipes*  
*Pagurus hirsutiusculus*  
*Pagurus samuelis*  
*Paracerceis cordata*  
*Parallorchestes ochotensis*  
*Paraxanthia taylori*  
*Pollicipes polymerus*

## APPENDIX 2. Continued.

*Polycheria osborni*  
*Porcellio americanus*  
*Pugettia gracilis*  
*Pugettia producta*  
*Romaleon antennarium*  
*Scyra acutifrons*  
*Semibalanus cariosus*  
*Tetraclita rubescens*

CNIDARIA

*Allopora porphyra*  
*Anthopleura elegantissima*  
*Anthopleura sola*  
*Anthopleura xanthogrammica*  
*Aurelia aurita*  
*Balanophyllia elegans*  
*Corynactis californica*  
*Epiactis prolifera*  
*Obelia* sp.  
*Stylianthea porphyra*  
*Symplectoscyphus turgidus*  
*Tethya aurantia*  
*Tubularia crocea*  
*Urticina lofotensis*

ECHINODERMATA

*Amphiodia occidentalis*  
*Amphipholis squamata*  
*Dermasterias imbricata*  
*Henricia leviuscula*  
*Leptasterias hexactis*  
*Leptasterias pusilla*  
*Loxorhynchus crispatus*  
*Ophiopholis aculeata*  
*Ophiothrix spiculata*  
*Pisaster giganteus*  
*Pisaster ochraceus*  
*Pycnogonum stearnsi*  
*Pycnopodia helianthoides*  
*Strongylocentrotus droebachiensis*  
*Strongylocentrotus franciscanus*  
*Strongylocentrotus purpuratus*

ENTOPROCTA

*Barentsia benedeni*

BRYOZOA

*Flustrellidra corniculata*  
*Integripelta bilabiata*

MOLLUSCA

*Acmaea mitra*  
*Alia tuberosa*  
*Amphissa columbiana*  
*Amphissa versicolor*  
*Anisodoris nobilis*  
*Balcis thersites*  
*Barleeia haliotiphila*  
*Barleeia subtenuis*  
*Berthella californica*  
*Bittium eschrichtii*  
*Cadlina luteomarginata*  
*Cadlina modesta*  
*Calliostoma annulatum*  
*Calliostoma canaliculatum*  
*Calliostoma ligatum*  
*Chama arcana*  
*Chlorostoma brunnea*

## APPENDIX 2. Continued.

*Chlorostoma funebris*  
*Corolla spectabilis*  
*Crassadoma giganteum*  
*Crepidula adunca*  
*Crepidula perforans*  
*Crepidatella lingulata*  
*Cryptochiton stelleri*  
*Cryptomya californica*  
*Cyanoplax dentiens*  
*Cymakra aspera*  
*Diodora aspera*  
*Diplodonta orbella*  
*Dirona picta*  
*Epitonium tinctum*  
*Flabellina trilineata*  
*Granulina margaritula*  
*Haliotis cracherodii*  
*Haliotis rufescens*  
*Hermisenda crassicornis*  
*Hiatella arctica*  
*Hipponix craniodes*  
*Irus lamellifer*  
*Ischnochiton regularis*  
*Katharina tunicata*  
*Kellia laperousii*  
*Lacuna cistula*  
*Lacuna marmorata*  
*Lacuna porrecta*  
*Lacuna unifasciata*  
*Lasaea subviridis*  
*Lirobittium purpureum*  
*Littorina keenae*  
*Littorina scutulata*  
*Littorina sitkana*  
*Lottia asmi*  
*Lottia digitalis*  
*Lottia gigantea*  
*Lottia insessa*  
*Lottia instabilis*  
*Lottia limatula*  
*Lottia pelta*  
*Lottia persona*  
*Lottia scabra*  
*Lottia scutum*  
*Lottia strigatella*  
*Lottia triangularis*  
*Megatebennus bimaculatus*  
*Milneria minima*  
*Modiolus capax*  
*Modiolus carpenti*  
*Mopalia ciliata*  
*Mopalia muscosa*  
*Musculus pygmaeus*  
*Mytilus californianus*  
*Nassarius mendicus*  
*Nuttallina californica*  
*Ocenebrina atropurpurea*  
*Ocenebrina interfossa*  
*Ocenebrina lurida*  
*Octopus dofleini*  
*Octopus rubescens*  
*Odostomia* sp.  
*Okenia rosacea*  
*Onchidella borealis*

## APPENDIX 2. Continued.

*Opalia wroblewskyi*  
*Placiphorella velata*  
*Penitella conradi*  
*Penitella turnerae*  
*Petricola carditoides*  
*Philobrya setosa*  
*Protothaca staminea*  
*Rostanga pulchra*  
*Tonicella lineata*  
*Tonicella lokii*  
*Transennella tantilla*  
*Trimusculus reticulatus*  
*Triopha catalinae*  
*Triopha maculata*

## PORIFERA

*Anaata spongigartina*  
*Antho lithophoenix*  
*Aplysilla glacialis*  
*Aplysilla polyraphis*  
*Axocelita originalis*  
*Clathria* sp.  
*Geodia mesotriaenae*  
*Halichondria panicea*  
*Haliclona* sp.  
*Higginsia* sp.  
*Leucandra heathi*  
*Leucilla nuttingi*  
*Leucosolenia eleanor*  
*Lissodendoryx topsenti*  
*Mycale psila*  
*Myxilla incrustans*  
*Ophlitaspongia pennata*  
*Scypha* sp.  
*Stelletta clarella*  
*Suberites* sp.  
*Tedania gurjanovae*  
*Tethya aurantium*

## SIPUNCULA

*Phascolosoma agassizii*

## CHORDATA TUNICATA

*Aplidium californicum*  
*Archidistoma eudistoma*  
*Archidistoma ritleri*  
*Cystodytes lobatus*  
*Didemnum carnulentum*  
*Pycnoclayella stanleyi*  
*Ritterella aequalisphonis*  
*Styela montereyensis*

## APPENDIX 3. South Farallon Islands intertidal fish species inventory, as of February 2011.

## CHORDATA (FISH)

*Clinocottus acuticeps*  
*Clinocottus embryum*  
*Clinocottus recalvus*  
*Gobiesox maeandricus*  
*Oligocottus maculosus*  
*Oligocottus snyderi*  
*Xiphister mucosus*

## APPENDIX 4. South Farallon Islands intertidal algae species inventory, as of February 2011.

## CHLOROPHYTA

*Acrosiphonia coalita*  
*Blidingia minima* var. *vexata*  
*Bryopsis corticulans*  
*Cladophora columbiana*  
*Cladophora graminea*  
*Codium fragile*  
*Codium setchellii*  
*Derbesia marina*  
*Endophyton ramosum*  
*Entocladia viridis*  
*Prasiola meridionalis*  
*Ulothrix flacca*  
*Ulva californica*  
*Ulva clathrata*  
*Ulva compressa*  
*Ulva conglobata*  
*Ulva flexuosa*  
*Ulva intestinalis*  
*Ulva lactuca*  
*Ulva lobata*  
*Ulva taeniata*  
*Urospora* sp.

## OCHROPHYTA

*Alaria marginata*  
*Analipus japonicus*  
*Colpomenia peregrina*  
*Compsomena serpens*  
*Costaria costata*  
*Desmarestia herbacea*  
*Desmarestia munda*  
*Dictyonium californicum*  
*Egregia menziesii*  
*Hinksia sandriana*  
*Laminaria ephemera*  
*Laminaria setchellii*  
*Laminaria sinclairii*  
*Leathesia difformis*  
*Melanosiphon intestinalis*  
*Petalonia fascia*  
*Petrospongium rugosum*  
*Pterygophora californica*  
*Pylaiella* sp.  
*Ralfsia* sp.  
*Scytosiphon dotyii*  
*Scytosiphon lomentaria*  
*Spongonema tomentosum*  
*Stephanocystis osmundacea*

## RHODOPHYTA

*Acrochaetium* sp.  
*Ahnfeltiopsis leptophylla*  
*Ahnfeltiopsis linearis*  
*Anotrichium furcellatum*  
*Antithamnion dendroidum*  
*Audouinella subimmersa*  
*Bangia* sp.  
*Bornetia californica*  
*Bossiella dichotoma*  
*Bossiella plumosa*  
*Bossiella schmittii*  
*Branchioglossum bipinnatifidum*  
*Branchioglossum undulatum*  
*Calliarthron tuberculatum*  
*Callithamnion biseriatum*

## APPENDIX 4. Continued.

*Callithamnion pikeanum*  
*Callophyllis crenulata*  
*Callophyllis flabellulata*  
*Callophyllis heanophylla*  
*Callophyllis linearis*  
*Callophyllis obtusifolia*  
*Callophyllis pinnata*  
*Callophyllis violacea*  
*Centroceras clavulatum*  
*Ceramium gardneri*  
*Ceramium pacificum*  
*Chondracanthus canaliculatus*  
*Chondracanthus corymbiferus*  
*Chondracanthus exasperatus*  
*Chondracanthus harveyanus*  
*Chondracanthus spinosus*  
*Clathromorphum parvum*  
*Constantinea simplex*  
*Corallina chilensis*  
*Corallina vancouveriensis*  
*Corallophila eatonianum*  
*Cryptopleura corallinara*  
*Cryptopleura lobulifera*  
*Cryptopleura ruprechtiana*  
*Cryptopleura violacea*  
*Cumagloia andersonii*  
*Delesseria decipiens*  
*Dilsea californica*  
*Endocladia muricata*  
*Erythrophyllum delesserioides*  
*Erythrotrichia carnea*  
*Farlowia compressa*  
*Farlowia conferta*  
*Farlowia mollis*  
*Faucheocolax attenuata*  
*Gelidium coulteri*  
*Gelidium robustum*  
*Gloiocladia laciniata*  
*Goniotrichopsis sublittoralis*  
*Gracilariophila oryzoides*  
*Gracilariopsis andersonii*  
*Grateloupia californica*  
*Grateloupia filicina*  
*Griffithsia pacifica*  
*Gymnogongrus chiton*  
*Halosaccion glandiforme*  
*Halymenia schizymenioides*  
*Herposiphonia parva*  
*Herposiphonia plumula*  
*Hildenbrandia occidentalis*  
*Hymenena flabelligera*  
*Hymenena multiloba*  
*Janczewskia gardneri*  
*Leachiella pacifica*  
*Lithophyllum dispar*  
*Lithothrix aspergillum*  
*Maripelta rotata*  
*Mastocarpus jardinii*  
*Mastocarpus papillatus*  
*Mazzaella affinis*  
*Mazzaella californica*  
*Mazzaella flaccida*  
*Mazzaella leptorhynchus*  
*Mazzaella linearis*  
*Mazzaella oregona*

## APPENDIX 4. Continued.

*Mazzaella parksii*  
*Mazzaella rosea*  
*Mazzaella splendens*  
*Mazzaella volans*  
*Melobesia marginata*  
*Melobesia mediocris*  
*Membranoptera dimorpha*  
*Mesophyllum lamellatum*  
*Microcladia borealis*  
*Microcladia coulteri*  
*Myriogramme spectabilis*  
*Myriogramme variegata*  
*Neogastroclonium subarticulatum*  
*Neoptilota densa*  
*Neoptilota hypnoides*  
*Neorhodomela larix*  
*Nienburgia andersoniana*  
*Odonthalia floccosa*  
*Opuntiella californica*  
*Osmundea spectabilis*  
*Peyssonnelia sp.*  
*Peyssonneliopsis epiphytica*  
*Phycodryis setchellii*  
*Pikea californica*  
*Pikea pinnata*  
*Pleonosporium vancouverianum*  
*Plocamium pacificum*  
*Plocamium violaceum*  
*Polyneura latissima*  
*Polysiphonia hendryi*  
*Polysiphonia pacifica*  
*Porphyra perforata*  
*Prionitis lanceolata*  
*Prionitis linearis*  
*Prionitis sternbergii*  
*Pseudolithophyllum neofarlowii*  
*Pterochondria woodii*  
*Pterocladia caloglossoides*  
*Pterosiphonia baileyi*  
*Pterosiphonia bipinnata*  
*Pterosiphonia dendroidea*  
*Pterothamnion villosum*  
*Ptilota filicina*  
*Ptilothamnionopsis lejolisea*  
*Pugetia fragilissima*  
*Pyropia gardneri*  
*Pyropia lanceolata*  
*Pyropia nereocystis*  
*Pyropia perforata*  
*Rhodochorton purpureum*  
*Rhodymenia californica*  
*Rhodymenia callophyllidoides*  
*Rhodymenia pacifica*  
*Rhodymeniocolax botryoides*  
*Sahlingia subintegra*  
*Sarcodiotheca gaudichaudii*  
*Schimmelmannia plumosa*  
*Scinaia confusa*  
*Smithora naiadum*  
*Stenogramma interrupta*  
*Stylonema alsidii*  
*Tiffaniella snyderae*  
*Weeksia reticulata*  
 TRACHEOPHYTA  
*Phyllospadix scouleri*