NOVEMBER
2018

policy matters

california senate OFFICE OF RESEARCH

CATASTROPHIC LOSS OF BULL KELP FORESTS

The number of living creatures of all Orders, whose existence intimately depends on the kelp, is wonderful... I can only compare these great aquatic forests of the southern hemisphere with the terrestrial ones in the intertropical regions. Yet if in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here, from the destruction of the kelp.

—Charles Darwin, June 1, 1834, Tierra del Fuego, Chile[1]

The kelp forests of California are one of the most diverse and productive ecosystems in the state, providing a home to more than 800 species of plants and animals.[2] Beginning in 2013, a "perfect storm" of kelp stressors led to the loss of more than 93 percent of the bull kelp along the coast of Northern California.[3] The sudden and widespread loss of bull kelp forests represents an unprecedented catastrophe that has severely affected the environmental, economic, and recreational health of the coastal region, particularly for Sonoma and Mendocino counties.

At the request of Senator Robert Hertzberg, chair of the Senate Natural Resources and Water Committee, we investigated the loss of kelp forests in California's coastal waters by interviewing experts and reviewing the relevant literature on the topic.

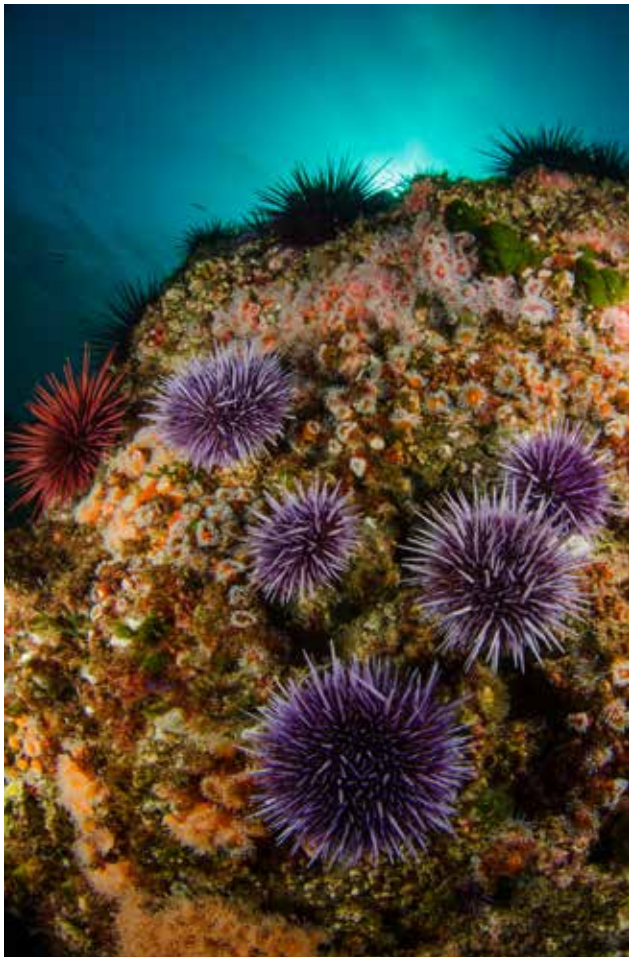
Available evidence suggests the kelp forests could take decades or even centuries to recover naturally.[4] However, a growing body of evidence from around the world shows that active restoration and management efforts can help promote the rapid recovery of kelp forests. Building on this knowledge, efforts are under way to assess the condition of Northern California's kelp forests and identify ways to promote their recovery.[5]

BACKGROUND

Kelp are species of large brown algae—or seaweed—that inhabit cold-water coastal regions around the world.[6] Canopy-forming kelp extend from the rocky seafloor to

the ocean surface to create complex, three-dimensional forest habitats that are home to a rich diversity of plants and animals. Kelp forest habitats rival tropical rainforests in their diversity and productivity. The coast of California is dominated by two species of canopy-forming kelp: giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*).[7] Giant kelp occurs from Baja California north to Point Año near Santa Cruz, whereas bull kelp occurs from Alaska south to Point Conception near Santa Barbara. Where ranges of the two species overlap along the Central California coast, bull kelp and giant kelp occur together.

Kelp is an important resource for the state, both on its own and as a habitat for other species.[8] Over the past 100 years, kelp has been harvested for a variety of uses, including as a food source for people and animals, fertilizer, a component of gunpowder and explosives, and as a source of algin, a thickening agent used in a wide variety of food and industrial applications. Historically, California's kelp-harvesting industry has had a greater presence in Southern California and was valued at $30 million annually in 2001.[9]



California kelp forests provide a home to more than 800 species of plants and animals.[10] Many of the species that depend on kelp have important commercial, recreational, and ecological value for the state, including sea otters, abalone, spiny lobster, sea urchins, and many species of fish.

CONDITIONS THAT NEGATIVELY IMPACT KELP

The density and abundance of kelp forests naturally fluctuate in response to changing conditions.[11] Kelp abundance is sensitive to climatic events, water temperatures, pollution, disease, and grazing. For example, kelp thrives in nutrient-rich cold waters but has poor survival in warmer waters. California kelp forests typically decline temporarily during years with warmwater El Niño events. Kelp also has been subject to broader-scale declines over the past several decades, likely tied to an overall warming trend of ocean waters.

COLLAPSE OF KELP FORESTS INTO URCHIN BARRENS

Kelp forests are particularly vulnerable to overgrazing from herbivorous sea urchins, which can trigger the collapse of the diverse and productive kelp ecosystem into a desolate barren of urchins.[12] The shift from a healthy kelp forest to a low-productivity urchin barren has been widely reported throughout the world, including along the

coasts of the United States, Canada, Norway, Japan, Chile, and Australia. Cases of kelp forest collapse have been documented worldwide many times over the last century, and archaeological studies have found evidence of a kelp-to-urchin barren transition more than 2,000 years ago off the Aleutian archipelago.[13]

In many cases, the collapse of a kelp forest is triggered by the loss of urchin predators in a region, either from disease or overexploitation by humans. With the predators gone, the sea urchins stop passively feeding on drift kelp filtered from the water column and instead form active feeding fronts that swarm across the landscape to feed directly on kelp plants. Urchin swarms can quickly decimate a kelp forest by chewing through the base of the plants. With the kelp gone, the hundreds of other species that rely on kelp for food and habitat also quickly disappear from the region, leaving behind bare rocks covered in urchins and little else.

The resulting urchin barrens are stable habitats that can prevent the recovery of kelp. With little food available, starving urchins scour the rocks and quickly consume any new kelp that attempts to grow in the barren. The barrens also provide excellent conditions for new larval urchins to settle out of the water column, ensuring the density of urchins in a barren remains high. Urchin barrens have been known to persist for decades and even centuries until disease or recovered predator populations reduce urchin numbers enough to allow kelp to recover. For example, urchin barrens formed along the western coast of Canada in the 1800s following overhunting of sea otters for the fur trade. Kelp forests began to recover in the late 1900s after the reintroduction of sea otters, but in regions where sea otters have not repopulated, barrens have persisted for 200 years.[14]

RESTORATION OF KELP FORESTS

Persistent urchin barrens have replaced productive kelp forests in regions around the world, prompting a growing interest in developing restoration actions to promote the recovery of kelp and its dependent species such as abalone. Examples of efforts to restore kelp forests include projects by:

- The Bay Foundation in Palos Verdes[15]
- Parks Canada in Gwaii Haanas, British Columbia, Canada[16]
- Scientific projects in Hokkaido, Japan[17]

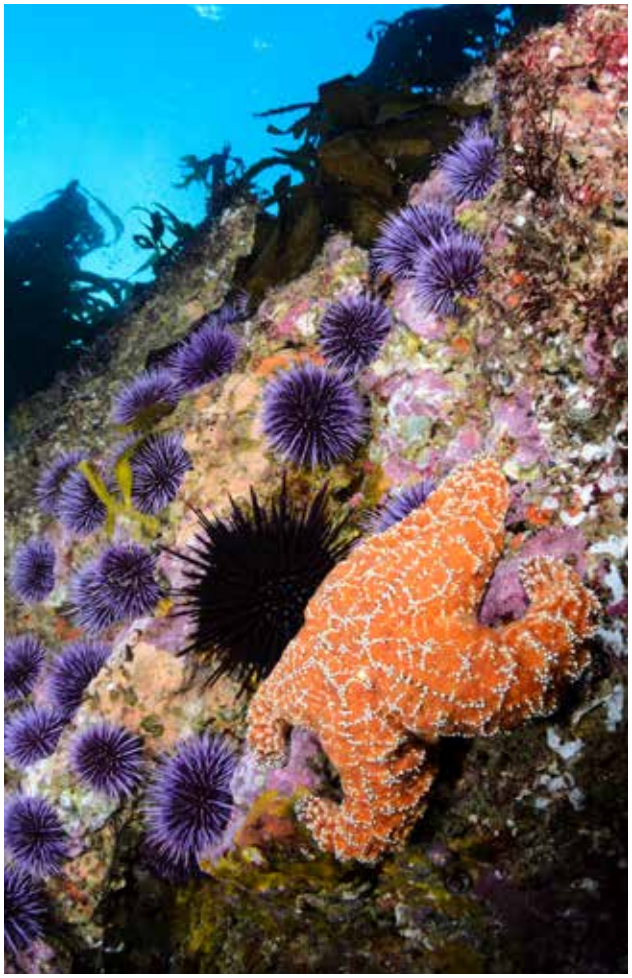
The projects have found that dramatically reducing urchin densities, either by manual removal or by lethal smashing of urchins by divers, can promote the recovery of kelp. In some cases, kelp quickly began to regrow in areas cleared of urchins, allowing the kelp forest to recover within months of the restoration efforts. The recovery of a kelp forest following reductions in urchin densities also depends on the growth cycle of the particular species of kelp, the environmental conditions that favor kelp growth, and the health of the local urchin predator populations.

RECENT COLLAPSE OF NORTH COAST KELP FORESTS

Over the last five years, the coast of Northern California has experienced a "perfect storm" of negative impacts, resulting in the loss of more than 93 percent of the bull kelp forests.

SEA STAR DIE-OFF

In Northern California, sea stars (also called starfish) are important urchin predators that help maintain healthy kelp forests by keeping urchin populations low. In 2013–14, an epidemic of sea star wasting syndrome (SSWS) along the Pacific Coast of North America resulted in one of the worst known marine mass mortality events in the world.[18] The highly contagious disease quickly spread through sea star populations and caused lesions, necrosis, and loss of limbs in infected individuals, leading to rapid degradation and death.[19] Millions of sea stars along the coast of California melted into piles of slime as a result of the outbreak.



Localized SSWS outbreaks have occurred in the past in California, typically during warmwater El Niño events.[20] From 2014–16, ocean temperatures along the Pacific Coast of North America reached record high values due to the combination of a marine heat wave (aka the "warm blob") and a strong El Niño event.[21] Research on the 2014 SSWS outbreak found that increased water temperatures likely contributed to the rapid spread and severity of the epidemic among sea stars.[22]

FORMATION OF URCHIN BARRENS

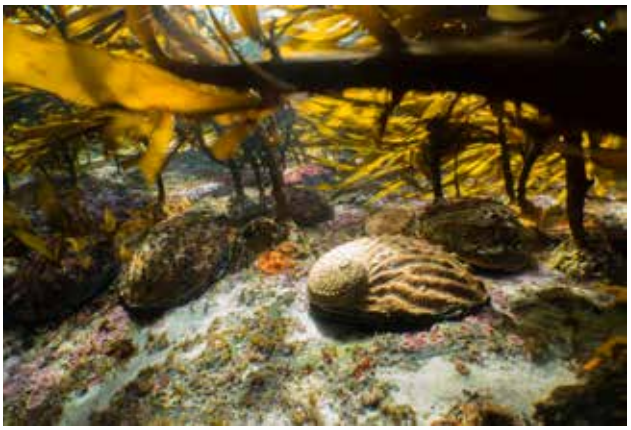
Following the crash of the sea star populations, the purple sea urchin population dramatically increased along the north coast of California. California Department of Fish and Wildlife (CDFW) researchers found urchin densities increased to 60 times greater than normal along hundreds of miles of coastline.[23] The combination of high water temperatures, which limits the growth of kelp, and increased urchin populations, which increases the destructive grazing of kelp, resulted in the loss of more than 93 percent of the bull kelp forests in Northern California.

Although the SSWS epidemic severely impacted sea star populations along the entire Pacific Coast of North America, the bull kelp forests in Northern California appear to have suffered much greater losses compared with other regions. Giant kelp forests in Southern California and bull kelp forests north of the state did not experience

the same widespread collapse into urchin barrens. Although it is not yet clear why kelp forests in some regions along the Pacific Coast experienced greater losses than other regions, the different responses could be due in part to the presence of other important urchin predators, such as sea otters or spiny lobster. Research on the impacts of the recent SSWS epidemic in British Columbia found that despite the loss of sea stars, sea otters continued to impact urchin densities and kelp abundance declined by only 30 percent.[24] Sea otters have been absent in Northern California following widespread declines in the 1800s due to overhunting for the fur trade.

CONSEQUENCES OF KELP DEFORESTATION

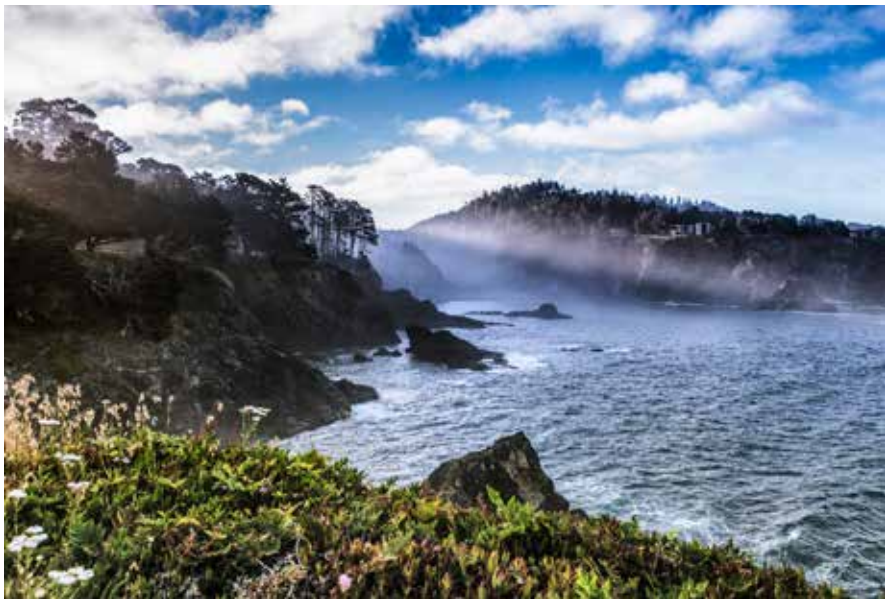
The collapse of kelp forests into urchin barrens along California's north coast has affected the ecological, recreational, and economic health of the region. Abalone depend on kelp for food, and the loss of kelp forests in Northern California led to a severe decline in the red abalone populations. CDFW manages the recreational red abalone fishery under the Abalone Recovery and Management Plan.[25] The Fish and Game Commission regulates the recreational take of abalone. In response to wide-sweeping declines in abalone density, the commission adopted regulations in December 2017 to close the recreational abalone fishery for the 2018 season (Section 29.15, Title 14, California Code of Regulations). Since the fishery's closure, CDFW has found no substantial positive changes in abalone conditions. In response, the commission proposed extending the recreational abalone fishery's closure for an additional two years, until April 1, 2021, to promote recovery of the red abalone population.[26] Before its closure, the recreation abalone fishery was valued at $44 million annually.[27]



Despite an overabundance of urchins, the loss of kelp forests also has hurt Northern California's commercial urchin fishery. The lack of food for barren urchins, compared with those living in kelp forests, results in shrunken, poor-quality gonads, which are marketed as uni for sushi.[28] Before the loss of kelp, the commercial red urchin fishery was valued at $3 million annually.[29] The commercial red urchin fishery in 2015 experienced a 66 percent drop in value following the loss of kelp along the north coast.[30] According to commercial urchin divers in the Fort Bragg area, many commercial boats have stopped operating the fishery in the region in the past few years, and those that continue to operate have experienced severe drops in productivity.

KELP RECOVERY EFFORTS IN NORTHERN CALIFORNIA

A coalition of public, nonprofit, and private stakeholders have convened the Kelp Recovery Working Group to assess the condition of the north coast bull kelp forests.[31] Group members include CDFW, the Ocean Protection and Greater Farallones Sanctuary Advisory councils, the Nature Conservancy, the California Sea Urchin Commission, and the Watermen's Alliance, along with many others.[32] The group has been working over the past year to develop management, restoration, and research



projects to promote the recovery of the north coast bull kelp forests and affected fisheries. The group will release its recommendations at the Greater Farallones Sanctuary Committee meeting on November 14, 2018, in San Francisco.[33] The group also plans to release a final technical report on its findings in February 2019.

Although other regions have shown success in kelp restoration by the manual removal or smashing of urchins, the specific conditions of California's north coast present many unique challenges.[34] The main challenge is the vast size of the affected area and the relatively harsher conditions that limit when and where divers can safely work. Manual reduction of urchin densities is incredibly labor-intensive, and current practices are inadequate to address the hundreds of miles of affected coastline. Additionally, bull kelp is an annual plant, so bull kelp forests need to be reseeded each year from a spore bank. With more than 93 percent of the bull kelp in the region lost and no longer producing spores, there is concern that a diminished spore bank could impede the recovery of kelp forests after urchin removal. The working group has been considering ways to selectively target and scale up restoration efforts to best promote sustainable recovery of the kelp forests.

Over the past year, working group members have initiated several pilot projects to assess the feasibility of possible restoration efforts. To promote recreational take of sea urchins to assist with the recovery of kelp, the Fish and Game Commission approved emergency regulations to increase the daily bag and possession limit for purple sea urchins in Sonoma and Mendocino counties.[35] Effective May 10 through November 6, 2018, the recreation bag limit increased from 35 sea urchins per day to 20 gallons per day (Section 29.11, Title 14, CCR). The emergency regulations were deemed necessary to reduce urchin populations to promote the recovery of kelp and red abalone populations.

The Watermen's Alliance consortium of California spearfishing clubs, in partnership with CDFW, has organized several urchin cleanup events by recreational sports divers to assess their potential to contribute to kelp recovery. A hundred sports divers collected about 7,100 pounds of urchins—56,800 individuals—during the first event over the 2018 Memorial Day weekend at Ocean Cove in Sonoma County.[36] A second cleanup event took place July 21–22 at Albion Cove in Mendocino County,[37] followed by another cleanup at Ocean Cove on September 29–30. The Watermen's Alliance also has raised money to pay commercial divers to remove urchins from targeted bays along the north coast, including Caspar Bay. CDFW staff are monitoring the effects of the higher sea urchin bag limit, volunteer cleanup events, and targeted bay clearing by

commercial divers to gauge their potential to contribute to the bull kelp's recovery.

POLICY CONSIDERATIONS

The recent widespread collapse of bull kelp forests into unproductive urchin barrens in Northern California represents an ecological catastrophe that has severely impacted the environmental, economic, and recreational health of the coastal region. In particular, the loss of 93 percent of the bull kelp forests has resulted in a large-scale die-off of abalone, prompting the closure of the recreational abalone fishery, and widespread starving of urchins, resulting in a 66 percent drop in the value of the commercial urchin fishery.

Given the persistent nature of urchin barrens, it is unlikely that kelp forests will be able to naturally recover in the foreseeable future. Promoting the recovery and resiliency of Northern California's bull kelp forests would be beneficial to the coastal region. Some possible actions to consider include:

▶ *Promote restoration efforts to reduce urchin densities.*

Bull kelp forests will be unable to recover until urchin densities are dramatically reduced. Restoration efforts in other regions of the world have demonstrated that having divers manually remove or smash urchins can promote the rapid recovery of kelp forests. The Kelp Recovery Working Group is developing recommended actions for kelp recovery efforts specific to the Northern California region. The recommendations are expected to be released in November 2018 with a final technical report in February 2019.

▶ *Improve resiliency of the bull kelp ecosystem.*

Kelp forests are more resilient to destructive overgrazing by urchins when multiple species of urchin predators are present in the ecosystem. Efforts to promote the recovery of sea stars and to reintroduce historic urchin predators such as sea otters to the region would improve the resiliency of Northern California bull kelp forests against collapse into urchin barrens.

▶ *Take action against climate change.*

The unprecedented warming of ocean water temperatures in California from 2014–16 contributed to the severity of the SSWS epidemic and to the loss of kelp. California's coastal ocean temperatures have increased over the past century in response to increasing greenhouse gas emissions, and climate model simulations suggest the warming trend will continue. Continued action to address the threat of climate change and reduce greenhouse gas emissions would help promote healthy kelp forests. ■

APPENDIX: LIST OF INTERVIEWS

Bay Foundation
July 7, 2018
Tom Ford, executive director

California Department of Fish & Wildlife
July 9, 2018
Cynthia Catton, Ph.D.,
environmental scientist
Laura Rodgers-Bennett, Ph.D.,
senior environmental scientist

California State University, Northridge
July 9, 2018
Mark A. Steele, Ph.D., professor
Department of Biology

California State Polytechnic University, Pomona
July 3, 2018
Jeremy Claisse, Ph.D., assistant professor
Biological Sciences Department

Commercial Urchin Divers
August 29, 2018: Jon Holcomb
August 29, 2018: Grant Downie
September 7, 2018: Ken Gerken

Greater Farallones Association
September 18, 2018
Rietta Hohman

Parks Canada
September 6, 2018
Lynn Lee, Ph.D., marine ecologist
Gwaii Haanas National Park Reserve

Watermen's Alliance
August 23, 2018
Joshua Russo, president

ENDNOTES

1. Charles Darwin, *Voyage of the Beagle*, 1909.
2. California Department of Fish and Game Marine Region, "Annual Status of the Fisheries Report Through 2003," report to the Fish and Game Commission as directed by the Marine Life Management Action of 1998, December 2004.
3. California Department of Fish and Wildlife, "'Perfect Storm' Decimates Northern California Kelp Forests," March 30, 2016.
4. Karen Filbee-Dexter and R. Scheibling, "Sea Urchin Barrens as Alternative Stable States of Collapsed Kelp Ecosystems," *Marine Ecology Progress Series*, vol. 495, 2014, p. 1–25.
5. https://farallones.org/kelp/.
6. Karen Filbee-Dexter and R. Scheibling, "Sea Urchin Barrens as Alternative Stable States of Collapsed Kelp Ecosystems," *Marine Ecology Progress Series*, vol. 495, 2014, p. 1–25.
7. California Department of Fish and Game Marine Region, "Annual Status of the Fisheries Report Through 2003," report to the Fish and Game Commission as directed by the Marine Life Management Action of 1998, December 2004.
8. Ibid.
9. California Department of Fish and Game Marine Region, "Annual Status of the Fisheries Report Through 2003," report to the Fish and Game Commission as directed by the Marine Life Management Action of 1998, December 2004.
10. Ibid.
11. Ibid.
12. Karen Filbee-Dexter and R. Scheibling, "Sea Urchin Barrens as Alternative Stable States of Collapsed Kelp Ecosystems," *Marine Ecology Progress Series*, vol. 495, 2014, p. 1–25; Kjell Magnus Norderhaug and H.C. Christie, "Sea Urchin Grazing and Kelp Revegetation in the NE Atlantic," *Marine Biology Research*, vol. 5, 2009, p. 515–528.
13. Karen Filbee-Dexter and R. Scheibling, "Sea

Urchin Barrens as Alternative Stable States of Collapsed Kelp Ecosystems," *Marine Ecology Progress Series*, vol. 495, 2014, p. 1–25.
14. Interview with Parks Canada staff.
15. http://www.santamonicabay.org/explore/in-the-ocean/kelp-forest-restoration/.
16. https://www.pc.gc.ca/en/pn-np/bc/gwaiihaanas/nature/conservation/restauration-restoration/nurture-nourrir.
17. Akira Watanuki et al, "Restoration of Kelp Beds on an Urchin Barren: Removal of Sea Urchins by Citizen Divers in Southwestern Hokkaido," *Bulletin of Fisheries Research Agency*, no. 32, 2010 p. 83–87.
18. Kevin D. Lafferty and E.E. Hofmann, "Marine Disease Impacts, Diagnosis, Forecasting, Management and Policy," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 371, no. 1689, March 2016, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4760133/.
19. Ian Hewson et al., "Densovirus Associated With Sea-Star Wasting Disease and Mass Mortality," *Proceedings of the National Academy of Sciences*, vol. 111, no. 48, 2014, p. 17,278–17,283, www.pnas.org/cgi/doi/10.1073/pnas.1416625111.
20. Ginny L. Eckert, J.M. Engle, and D.J. Kushner, "Sea Star Disease and Population Declines at the Channel Islands," *Proceedings of the Fifth California Islands Symposium* (Minerals Management Service, Washington D.C.), 1999, p. 390–393.
21. Jennifer Phillips et al., "California's Coast and Ocean Summary Report," California's Fourth Climate Change Assessment, August 2018, http://www.climateassessment.ca.gov/state/docs/20180827-OceanCoastSummary.PDF.
22. Morgan E. Eisenlord et al., "Ochre Star Mortality During the 2014 Wasting Disease Epizootic: Role of Population Size Structure and Temperature," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 371, no. 20150212, December 2015.
23. California Department of Fish and Wildlife, "'Perfect Storm' Decimates Northern California Kelp Forests," March 30, 2016.
24. Jenn M. Burt et al., "Sudden Collapse of a Mesopredator Reveals its Complementary Role in Mediating Rocky Reef Regime Shifts," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 285, no. 20180553, July 2018.
25. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=29494&inline.
26. Fish and Game Commission, "Initial Statement of Reasons for Regulatory Action to Amend Section 29.15, Title 14, California Code of Regulations. Re: Recreational Take of Red Abalone,"June 27, 2018.
27. California Department of Fish and Wildlife, "'Perfect Storm' Decimates Northern California Kelp Forests," March 30, 2016.
28. Jeremy T. Claisse et al, "Kelp Forest Habitat Restoration Has the Potential to Increase Sea Urchin Gonad Biomass," *Ecosphere*, vol. 4, no. 3, 2013, article 38.
29. California Department of Fish and Wildlife, "'Perfect Storm' Decimates Northern California Kelp Forests," March 30, 2016.
30. Ibid.
31. https://farallones.org/kelp/.
32. http://farallones.org/wp-content/uploads/2018/09/KRWG-Members.pdf.
33. https://farallones.noaa.gov/manage/sac_meetings.html.
34. Kelp Recovery Working Group, meeting notes for April 25, 2018, and August 2, 2018.
35. California Fish and Game Commission Finding of Emergency and Statement of Proposed Emergency Regulatory Action, April 3, 2018, https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=156724&inline.
36. Mary Callahan, "North Coast Divers Take the Plunge, Target Hordes of Purple Urchins," *Press Democrat*, June 6, 2018, https://www.pressdemocrat.com/lifestyle/8353809-181/north-coast-divers-take-the?sba=AAS&artslide=3.
37. Michelle Blackwell, "Urchin Cleanup to Help Kelp Held in Albion," *Mendocino Beacon*, July 26, 2018.

Written by Teresa Feo. The California Senate Office of Research is a nonpartisan office charged with serving the research needs of the California State Senate and assisting Senate members and committees with the development of effective public policy. The office was established by the Senate Rules Committee in 1969. For more information, please visit **http://sor.senate.ca.gov** or call **(916) 651-1500**.