Photo credit: Luis Lamar, Woods Hole Oceanographic Institution

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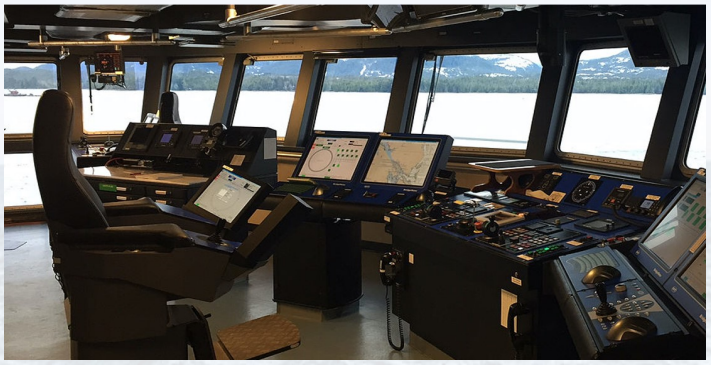
A view from the bridge



The ongoing pandemic interruptions to the academic research enterprise are acute. Ocean sciences has had particular challenges with field work and related travel being cancelled or delayed. Laboratory closures jeopardized planned and ongoing experiments, sample analyses, and living cultures and stocks. We acknowledge that many projects may fall short of their original goals and timelines which were developed before the pandemic. In the absence of additional funding, Programs must consider the tradeoffs of supplementing existing awards against the funding of new awards out of our current year budget.

There are several activities that PIs should be aware of that support the scientific workforce. OCE is rejuvenating its Postdoctoral Fellowship program (DCL 20-131). OCE participates in the new Mid-Career Advancement program (NSF 21-516). A recent Dear Colleague Letter clarifies and expands the scope of Career-Life Balance Supplements (NSF 21-021) for project support during occasions of family leave/dependent care.

We encourage PIs of currently funded projects impacted by the pandemic to:

1) communicate directly with Program Officers and to report the impacts of the pandemic on their projects in annual reports. Impacts can also be recorded via "Interim" reports in Research.gov. The advantage of recording impacts in the reporting system is that the information will become part of your award record, and thus will be easily accessible when communicating with Program Officers about your project in the future, for instance regarding extensions or supplements in the final year of the project *(PAPPG VII.D)*;

Continued on next page...

2) utilize no-cost extensions to compensate for time lost to closures and delays. For extensions that require NSF approval (generally, beyond the first twelve-month extension), the pandemic clearly falls under the "exceptional circumstances" required to justify the extension *(PAPPG VI.D.3.c)*.

3) use their considerable flexibility to re-budget funds across budget categories, in accordance with their institutions' policies and procedures, and in pursuit of their project's science goals *(PAPPG X.A.3)*; and

4) communicate with Program Officers before submitting a supplement request. We do not have new or separate funds for supplements; they must come from the regular program budget, so we do not expect supplements to be common. In general, supplement requests are considered in the last year of a project, after rescheduling and re-budgeting options have been utilized, and a full picture of both progress and impacts for a project can be assessed *(PAPPG VI.E.4)*.

We also recognize that each project is unique, and the range of possible impacts is large. It is impossible for us to devise general rules for supplements that would apply uniformly without exceptions. The Programs are committed to working with individual PIs and collectively determining the best course of action that will maximize the science returns and support the well-being of our entire science community. If you think a modest supplement can enhance the science output of your project, we encourage you to email your Program Officer with a brief description of the impacts, the management steps that have already been taken to mitigate them, and a strong justification of the need for and science impact of supplemental funding. Because every supplement has a direct impact on our ability to support new proposals, we ask that PIs exercise restraint, consider a supplement only after exhausting other possibilities as outlined above, and only ask for the minimum level of support needed.

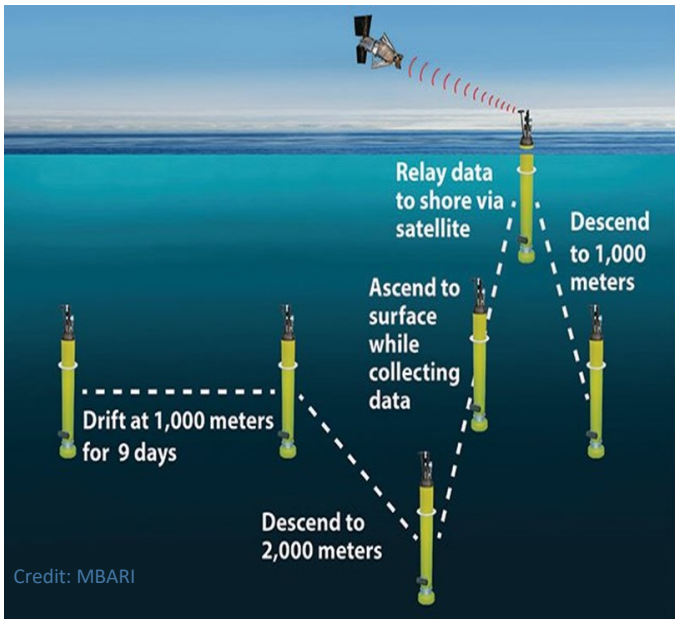
The past year has also been one where some exciting and important science has seen the light of day. In this short digest we highlight a small selection of some of the excellent NSF-funded science that has been published this Fall.

Stay safe and healthy,

Terry Quinn

Director of Ocean Sciences
National Science Foundation

New ocean sensor array funded by NSF



NSF has just awarded a new $53 million grant to create a world-wide fleet of robotic floats, transforming how we monitor the world's oceans.

The Global Ocean Biogeochemistry Array (GO-BGC Array) will collect biological and chemical data from 2 kilometers beneath the ocean, to the surface, with the data being made available immediately for researchers, educators and government agencies around the world. Data collected will include PH, nitrate levels, sunlight levels, and even the amounts of microscopic algae floating in the water. For the first time, these kinds of biological and chemical oceanographic data can be collected from the majority of the world's oceans and made available to all.

Several organizations are involved in the project, including the Monterey Bay Aquarium Research Institute (MBARI), the University of Washington, Princeton University, the Scripps Institution of Oceanography, and the Woods Hole Oceanographic Institution.

The project also includes an outreach program with workshops, hands-on activities, and educational materials to help scientists, teachers, and students learn to use the data from the sensor floats in the classroom, from elementary schools to grad schools.

For makers and technology tinkerers, courses based on GO-BGC technology will also be offered through "the Sandbox," a makerspace
(see https://materovcompetition.org/news)

For more details go to:
https://www.mbari.org/go-bgc-release/

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Scientists highlight the risk sea level rise poses to atoll island systems and their human communities

Atoll islands are created in tropical waters by the growth of coral reefs, but because of the way that they are formed they are low-lying, and do not protrude much above sea level. As such, they are vulnerable to sea level rise. Many atolls are inhabited by humans, as well as often supporting unique ecosystems. However, current levels of sea level rise are unprecedented, and have not been seen for the past 5000 years at the least. This sea level rise threatens these island systems.

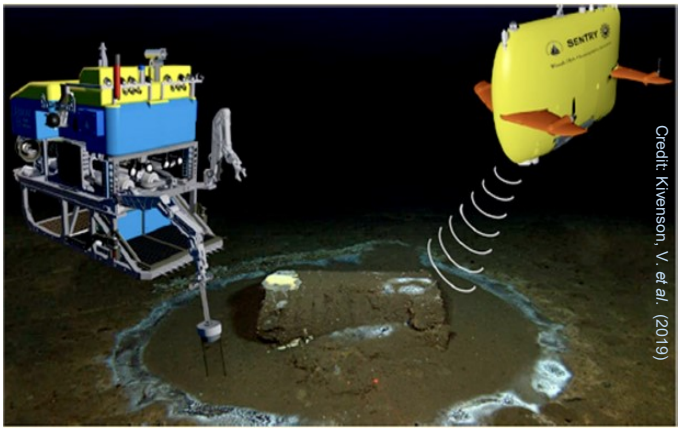
NSF-funded researchers developed a method to investigate the future of atolls in the face of sea level rise, by integrating fossil data, historical photographs, and modern observations of extreme tide and wave events to estimate when these island systems may become unstable.

Under a variety of climate change scenarios, all the atoll island systems studied became unstable in the middle of the 21st century. In the most likely climate change scenario, the rate of sea level rise tripled, and groundwater sources were permanently lost within the next few decades, with islands becoming unstable in the second half of this century. Under a more negative climate change scenario, the sea level rose by a meter, rendering the islands unstable in the next 20–40 years, and exposing human communities to intolerable levels of risk by the year 2060.

There is an urgent need to develop strategies and initiate engineering projects and other methods to protect these islands from sea level rise. An important consideration is that these human communities have developed unique cultures over millennia, and protection of the atolls from sea level rise also protects the identity of indigenous island communities on atoll islands.

Paper: Kane, H.H. & Fletcher, C.H. (2020). Rethinking reef island stability in relation to anthropogenic sea level rise. *Earth's Future* 8(10): e2020EF001525.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020EF001525

NSF infrastructure researchers discover evidence of "sloppy" disposal of toxic chemicals off the California coast



In 1972, the U.S. banned the domestic use of the toxic pesticide DDT due to concerns about its health impacts on humans and wildlife. Prior to this ban, one of the largest producers of DDT internationally was the Montrose Chemical Corporation, located in Los Angeles County. Between 1947 and 1961, the company dumped an estimated 2000−3000 barrels of DDT-related waste materials every month at sea, totaling ~1 million gallons of waste per year.

Underwater research vehicles were used to investigate potential DDT dumping sites off the coast of California. First of all, the autonomous underwater vehicle, *AUV Sentry,* surveyed the area with a multibeam echosounder looking for anomalies on the seabed that could have been dumped barrels. Then the remotely operated vehicle -*ROV Jason*- visually confirmed the dumped waste barrels and collected seabed sediment samples for analysis. Sixty barrels of waste were discovered, many of which had broken open or showed signs of having been punctured (possibly to help the barrels sink when dumped). The researchers described the way the toxic materials were discarded as "inherently sloppy."

Eighty-six percent of seabed surface sediment samples collected exceeded levels of DDT (and associated chemicals) at which toxic effects could occur, with the median level being nearly five times this toxic threshold. However, some hotspots exceeded the threshold for potential toxic effects by more than 160 times. The researchers were able to distinguish contamination from

this ocean dumping from contamination by discharges through sewers and storm drains, as the former contained distinct hydrocarbons used during the manufacture of DDT. Ocean dumping was found to be the main source of DDT contamination for more than 3000 km^2 of the region's deep seabed environment.

Paper: Kivenson, V. *et al*. (2019). Ocean dumping of containerized DDT waste was a sloppy process. *Environ. Sci. Technol.* 53: 2971−2980.
https://pubs.acs.org/doi/10.1021/acs.est.8b05859

Learning about climate change and ice sheet melting from ocean sediments

About 18,000 years ago the world's carbon dioxide levels increased, leading to a melting of ice sheets. NSF-funded scientists have just published a new study on the melting of the now extinct Cordilleran ice sheet during this period, to try to give us insight into what might happen to the Greenland and West Antarctic ice sheets in the face of current climate change.

These ice sheet melting—or "siku"—events (named after the Inupiat/Inuit word for ice) cause stony rubble and sediments to raft out to sea by icebergs breaking off the melting ice shelves. The scientists studied this deposition of sediments, dropped by melting icebergs in the Gulf of Alaska. They found that the melting of the Cordilleran ice sheet, and its flow into the Pacific, preceded melting of other ice sheets flowing into the North Atlantic by nearly 1.5 thousand years. This was surprising, as the assumption has been that warming of the North Atlantic would have had the biggest influence on melting ice sheets, warming and melting those first.

Paper: Walczak, M.H. *et al*. (2020). Phasing of millennial-scale climate variability in the Pacific and Atlantic Oceans. *Science 370 (6517): 716-720.*
https://science.sciencemag.org/content/early/2020/09/30/science.aba7096

New study finds a faster way to study remote penguin colonies by drones

Monitoring penguins in Antarctica is difficult—their colonies are both large and difficult to get to, and so surveys are often done from the air. Previously this was done with a helicopter or a single drone. Surveying with a helicopter gets good aerial images for analysis, but using a helicopter is expensive and the noise can disturb the penguins. A drone is largely ignored by the penguins, but they have a limited battery time, especially in the cold Arctic climate. However, NSF-funded graduate student Kunal Shah has developed a method that allowed rapid surveying of penguin colonies. What would have taken two days in the past can now be completed in under 3 hours. A small squadron of up to 4 drones were used to survey the penguin colonies, and the route of the drones was determined via the


Credit: ECM Parsons

"POPCORN" (Path Optimization for Population Counting with Overhead Robotic Networks) algorithm. This algorithm calculates the most efficient route for the drones, allowing fast but comprehensive surveys. The drones managed to survey two Adélie penguin (*Pygoscelis adeliae*) colonies on Ross Island, Antarctica. Over 300,000 penguins were surveyed at Cape Crozier, and 3000 penguins at a smaller colony at Cape Royds. More than 2000 images were taken in the surveys, which will be put together like a mosaic to study the entire colony sites. In addition to monitoring penguins more efficiently, with less impact on the birds, the drone system could also be used in many other ways; for example, to monitor the scope and scale of wildfires.

Paper: Shah, K. *et al. (2020).* Multidrone aerial surveys of penguin colonies in Antarctica. *Science Robotics* 5(47): eabc3000.
https://robotics.sciencemag.org/content/5/47/eabc3000

Researchers find a better way to monitor water quality on beaches in the tropics

Despite their ecological and economic importance, tropical coastal waters are infrequently studied. Moreover, tropical waters serve as a model for what the future may hold for other coastal regions in the face of the impacts of climate change.

The waters at a tropical beach in Costa Rica were analyzed for a number of microorganisms associated with sewage contamination.

Most microorganisms' concentrations were greater in the rainy season; however, norovirus was greatest in the dry season. Fecal indicator bacteria levels exceeded recreational water quality criteria standards in more than 85% of river samples but less than 50% of ocean samples. However, 100% of river samples and more than 89% of ocean samples contained other sewage-related markers, indicating chronic sewage contamination. Roughly a third of river samples also tested positive for a variety of human pathogens (disease-causing microbes such as *Giardia, Cryptosporidium, Salmonella,* and norovirus), although these specific pathogens were infrequent in ocean samples.

The researchers came up with two separate sets of best indicator microorganisms related to sewage contamination in ocean water and river water. In many countries, sewage contamination on recreational beaches is monitored only by recording levels of fecal indicator bacteria, like fecal coliforms and/or *Enterococci*. However, this study found that it is important to add at least one viral indicator when monitoring water quality, to best identify pathogens associated with unsafe swimming conditions in the tropics.

Paper: González-Fernández, A. *et al.* (2021). Relationships among microbial indicators of fecal pollution, microbial source tracking markers, and pathogens in Costa Rican coastal waters. *Water Research* 188, 116507.
https://www.sciencedirect.com/science/article/pii/S0043135420310423

North Atlantic waters are the warmest they have been for ~3000 years

Scientists analyzed sediments from a lake on Ellesmere Island, in the Arctic, to investigate historic sea surface temperatures in the region. They found that sediment samples in recent history (the past 150 years) correlated with sea surface temperatures in that region of the North Atlantic, allowing the sediments to be used to investigate sea surface temperatures over a 3000-year period. The study—which was partly funded by NSF—determined that sea surface temperatures in the North Atlantic were coldest from the late Middle Ages to just before the Industrial Revolution (1400s to 1800s), while current sea surface temperatures are the warmest they have been for roughly 2,900 years.

Paper: Lapointe, F. *et al.* (2020). Annually resolved Atlantic sea surface temperature variability over the past 2,900 y. PNAS 117 (44) 27171-27178.
https://www.pnas.org/content/117/44/27171

The rise and fall of coral reefs – how coral reef diversity changed during prehistoric global warming events

In the past 488 million years, there have been five mass extinctions and two additional global declines in coral and other reef species, all but one of which have been linked to global warming and ocean acidification. It is believed that stony, reef-building corals suffer particular impacts from these events, as the conditions affect the creation of, or even dissolve, their stony skeletons. When these species decline, however, it may provide opportunities for "soft corals" and their relatives (for example, sea anemones, black corals and octocorals) that lack a stony skeleton, or have a skeleton that is made from protein.

A recent study, by NSF-funded researchers, looked at samples from ancient coral reefs gathered from around the world, and examined the gain and loss of coral skeletal features over time, thereby building up an evolutionary history of coral diversity.

The study found that after these warming and carbon dioxide-linked coral mass extinctions and crises (and the late Devonian coral crisis, which was due to widespread low oxygen levels in the ocean), stony corals declined. There was in turn a diversification of other types of species, with sea anemones and soft corals with protein skeletons filling the empty ecological niches of extinct reef-building corals.

The researchers conclude that changing environmental conditions we are currently experiencing may lead to a decline in stony (aragonitic) reef-building (scleractinian) corals, but the evolutionary history of corals suggests that other groups will survive and diversify, taking over stony coral roles and ecological niches.

Paper: Quattrini, A.M. *et al.* (2020). Palaeoclimate ocean conditions shaped the evolution of corals and their skeletons through deep time. *Nat. Ecol .Evol*. 4: 1531–1538.
https://doi.org/10.1038/s41559-020-01291-1

Greenland ice loss could reach unprecedented rates in the next century

Greenland is likely to lose ice faster this coming century than at any time in the past 12,000 years. An NSF-funded study modelled the historical losses of Greenland ice, and found the largest pre-industrial rates of mass loss (up to 6,000 billion tonnes per century) near the beginning of the Holocene (10,000–7,000 years ago), i.e., at the end of the last ice age. This loss was similar to ice loss rates (6,100 billion tonnes per century) between 2000 and 2018. The modelled ice losses in the future, under high and low greenhouse gas emission scenarios, range from 8,800–10,600 billion tonnes per century for the low greenhouse gas emissions scenario, to 14,000–35,900 billion tonnes per century for the high emissions rate scenario. Unless major efforts are enacted to slow down the rate of climate change, the rate of ice loss over the next century could be 4 times greater than the highest rate seen in the previous 12,000 years. Moreover, the researchers predict that Greenland could be completely ice free within the next 1000 years.

Paper: Briner, J.P. *et al.* (2020). Rate of mass loss from the Greenland Ice Sheet will exceed Holocene values this century. *Nature* 586**:** 70–74.
https://www.nature.com/articles/s41586-020-2742-6?fbclid=IwAR1yFNlYG0H6iRT3eZZdwLWI1Xg_kqIgjsL2TQugidsFmZAepSc3wdOtiEg

Scientists find that coastal permafrost not as frosty as thought

Permafrost is brick-solid, frozen soil found in polar regions. It gets its name from the belief that it was “permanently frozen” year-round. The permanently frozen nature of permafrost was an important consideration when it comes to climate change, as it traps a huge amount of methane and carbon dioxide below its frozen surface. Scientists thought that the permafrost extended offshore, extending underneath shallow coastal waters. In addition to trapping carbon, it was believed that this solid coastal permafrost would also protect against coastal erosion.

However, a new NSF-funded study in Alaska has found that this is not the case. Researchers describe how they found that beaches and the shallow coastal area were, in fact, ice free to a depth of 65 feet, and not frozen solid at all. Moreover, on the nearby land, they found only the top 16 feet of the tundra to be frozen. This has major implications, as melting permafrost may release trapped greenhouse gases. Also, melting permafrost can accelerate coastal erosion, which poses a risk to human communities in coastal areas.

Paper: Pedrazas, M.N. et al. (2020). Absence of ice-bonded permafrost beneath an Arctic lagoon revealed by electrical geophysics. *Science Advances* 6(42), eabb5083
https://advances.sciencemag.org/content/6/43/eabb5083

Researchers predict even more plastic to enter the oceans

NSF-funded researchers estimated that in 2016, from 19 to 23 million metric tons, or 11% of global plastic waste, entered aquatic ecosystems. This figure does not even include microplastics or discarded fishing gear—a major source of ocean plastic.

If we carry on producing plastic waste at the current rates with no improvements to waste management, then this will be as much as 90 million metric tons by 2030. Even if we enact the ambitious waste reduction measures set by Governments (including G7, EU and UN commitments and plans), annual production will be from 20 to 53 million metric tons per year by 2030.

The researchers stated that without major technological innovation we cannot recover even 10% of annual plastic production from the environment.

Paper: Borrelle, S. *et al.* (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science* 369 (6510): 1515 -1518.
https://science.sciencemag.org/content/369/6510/1515

5000 years ago a cool climate period led to an increase in seabirds, who changed the ecosystem—through their droppings !

The tussac grassland areas of the sub-polar Falkland Islands are important breeding areas for seabirds. Over-grazing by sheep and erosion are having major impacts on this habitat. However, the potential impacts of climate change were unknown until a study by NSF-funded researchers investigated historical changes in climate, seabird presence and peat.

The researchers looked at a 14,000-year period, via a nearly 5 meter column of sampled peat. They found, at approximately 5000 years ago, that a cooling period led to the arrival of seabirds on the island—indicated by a change in the peat's chemical profile, caused by their guano or droppings. In turn, the guano from the seabirds increased local nutrients, helping tussac grass thrive and also increasing the production of peat. However, incidents of fire also increased, as indicated by charcoal in the core samples—possibly due to the grasses providing more fuel for wildfires.

Current conservation efforts for the tussac grasses need to take into account this link between seabirds and grass ecology. However, as the Falkland Islands seem to have been colonized by seabirds during a cool period, there is concern that a warming Southern Ocean may mean that the islands cease being suitable habitat for them, with the researchers warning that collapse of the seabird colonies could occur over just a matter of decades.

Paper: Groff, D.V. *et al*. (2020). Seabird establishment during regional cooling drove a terrestrial ecosystem shift 5000 years ago. *Science Advances* 6 (43): eabb2788.
https://advances.sciencemag.org/content/6/43/eabb2788

Climate-linked declines in rocky shore marine species

There has been concern that increasing amounts of carbon dioxide dissolving in ocean waters, and the resulting increase in acidity that this causes, might be having an impact on marine species with shells. In particular, mollusks with shells made from calcium carbonate might suffer as the acidic conditions (i.e., a reduction in ocean pH) hinder shell growth.

To investigate this, NSF-funded researchers looked at recruitment rates (the number of new animals each year) in the Gulf of Maine, a rocky shore environment which has seen a high rate of warming and low pH levels in recent years. The researchers found that the rate of mussel recruitment decreased by nearly 16% per year over the last two decades and barnacles decreased by 5% per year. The abundance of three common sea snails, periwinkles, limpets and dog whelks, decreased at a rate of just over 3% a year. Over the past two decades, the abundances of limpets, periwinkles, and dog whelks in this part of the Gulf of Maine declined by at least 50%, and the researchers predict that over the next 10–20 years there will be an additional 50% reduction in their abundance. These declines were correlated with changes in ocean temperature. These various species are ecologically important in their habitats, and their wholesale decline could fundamentally change the nature of the rocky shore ecosystem.

Petraitis, P.S. & Dudgeon, S.R. (2020). Declines over the last two decades of five intertidal invertebrate species in the western North Atlantic. *Communications Biol* 3, art. 591
https://www.nature.com/articles/s42003-020-01326-0

Contaminated fish deliver toxic mercury to the deepest parts of the ocean

Scientists examined mercury levels in snailfish and marine invertebrates (amphipods) in the Mariana Trench (6.9–10.2 km deep) near Guam and the Kermadec trench (6–10 km deep) near New Zealand—two of the deepest parts of the ocean. The scientists found the levels of mercury in these deep-sea marine organisms were similar to levels seen in fish from near the surface of the Pacific (~500m).

They concluded that surface fish become contaminated by mercury from human sources, as rainfall the Pacific pulls anthropogenic mercury in the atmosphere, and then deposits it in the ocean surface ecosystem. When these contaminated animals die, their carcasses sink to the ocean depths, taking the pollutants with them. As a result, large amounts of mercury have been transferred to remote, deep ocean trench food webs and ecosystems, causing elevated concentrations of mercury in deep sea marine species.

Blum, J.D. *et al.* (2020). Mercury isotopes identify near-surface marine mercury in deep-sea trench biota. *Proceedings of the National Academy of Sciences* 117(47): 29292-29298. https://www.pnas.org/content/117/47/29292

Researchers find a new virus associated with bleached corals

Coral reefs make up only 1% of the ocean's area, but they are globally important because of the diversity of species that inhabits them—nearly a quarter of all marine species. However, between 2014 and 2017, nearly three-quarters of the world's coral reefs experienced coral bleaching (i.e., when they lose their symbiotic organisms—zooxanthellae—that provide them with energy) and nearly 30% suffered mortality events because of the various stressors they face.

A new study funded by NSF, at the Mo'orea Coral Reef Long-Term Ecological Research site in French Polynesia, investigated the role that viruses play in the Health of coral reefs. The researchers conducted a genetic scan (using environmental genomic methods) of the coral samples and looked specifically at viruses with electron microscopy, to identify the microorganisms that were associated with healthy and bleached corals. They found nucleocytoplasmic large DNA viruses, or "NCLDs", and they analyzed the genetic makeup (genome) of an NCLD associated with coral that had undergone bleaching. The specific NCLD associated with bleached coral was a new discovery, and the researchers suggest that it is evolutionarily distinct. This NCLD was also found in healthy corals, but it was very abundant in bleached corals, leading the researchers to suggest that "it plays a role in the onset and/or severity of coral bleaching."

Messyasz, A. *et al.* (2020). Coral bleaching phenotypes associated with differential abundances of nucleocytoplasmic large DNA viruses. *Front. Mar. Sci.* 7:555474. doi: 10.3389/fmars.2020.555474 https://www.frontiersin.org/articles/10.3389/fmars.2020.555474/full