1. Coral Reefs
    a. This presentation is meant to communicate important aspects of coral reefs and climate change to school classes. It is by no means comprehensive but is meant to be a framework to understand the importance of coral reefs. The presentation is most appropriate for middle to high school groups and was written to help teach students the diversity of these natural ecosystems. If you have any questions, suggestions or comments you can contact the author, Raphael Ritson-Williams at raphswall@gmail.com. Raphael is a PhD student at the University of Hawaii who studies coral reefs and researchers ecology, evolution and conservation. He is funded by a STAR Fellowship Assistance Agreement # FP917660 awarded by the U.S. Environmental Protection Agency (EPA). This presentation has not been formally reviewed by EPA. The views expressed in this presentation are solely those of the authors, and EPA does not endorse any products or commercial services mentioned in this publication.
2. Corals Create Reefs
    a. Coral reefs are marine ecosystems found in clear, shallow tropical waters around the world, including Hawaii and Florida in the USA. Reefs provide habitat for diverse communities of animals and plants. Colonies of coral animals are the building blocks of these reefs. On a global scale corals can create huge reefs by building their limestone skeletons from the bottom of shallow oceans to the sea surface. The Great Barrier Reef is 1,600 miles long and can be seen from space. Coral reefs cover less than 0.1% of the ocean surface but they contain at least 25% of all marine species/diversity.
3. Global Value of Reefs
    a. These limestone reefs are really important to people, because they provide habitat for diverse species, seafood that we eat, protection of coastlines from wave damage, and a sustainable source of revenue from tourism. Globally, the estimates of coral reef economic values range widely but the values shown on the slide are a conservative estimate. Sponges and soft corals contain many different types of natural compounds that may be effective treatment for cancer or have antibacterial activity. Discovering natural products from coral reef animals, is a growing field because of the huge biodiversity found on reefs.
4. Hawai'ian Coral Reefs
    a. The reefs in Hawaii are valued at $800 million a year, mostly from the tourist dollars that they attract to the islands.
5. Coral Colonies Build Homes
    a. On a local scale coral reefs increase the "roughness" (rugosity) of the habitat and provide nooks and crannies that are used by marine animals as homes. This is comparable to an apartment building

providing structure for people in a city. This roughness is especially important for herbivorous fish as a place to hide from predators.

6. Corals' Cousins
    a. Coral colonies are important for reef habitats but what are they? Corals are animals. They are related to Portuguese man of war, jellyfish, soft corals, anemones, and zooanthids. All of these groups are classified in the phylum Cnidaria. Cnidarians are some of the oldest types of animals and have existed for at least 550 million years. Cnidarians have simple saclike bodies with tentacles surrounding their mouths. All cnidarians have microscopic harpoons (nematocysts) that they use to catch their food.
7. Coral Skeleton
    a. Of these related creatures, the hard corals are the only ones that produce a limestone skeleton. These skeletons are basically "cups" of limestone that the coral secretes to protect itself and live in. The living creature is actually a very thin layer of tissue that coats this skeleton. The skeleton of coral colonies form limestone rocks (that remain on reefs when the coral dies). On this brain coral you can see the exposed skeleton above. This coral is being eaten by disease, which removes the living tissue (the brown on the bottom half of this slide) and leaves bare skeleton.
8. Massive Coral Skeleton
    a. There are more than 800 different species of shallow water hard corals (scleractinians) and they are classified based on the shape of their skeletons. Some corals build massive colonies such as this species of *Porites*. These massive corals are slow growers but relatively resistant to stress.
9. Branching Coral Skeleton
    a. Some corals such as this branching species of Pocillopora can grow to the size of a small hedge and is home for many species of fish, snails, worms and many other small creatures.
10. Coral Individuals
    a. The coral individual is called a polyp, which have a very simple anatomy compared to fish and even most other invertebrates. They are basically a bag, one opening for their food and waste. We call this the taste it twice body plan!
    b. Think of a coral polyp as a small animal that fits in a cup, with its rim covered with sticky tentacles. A colony is made from tens to thousands of individual coral cups (called polyps) that grow next to each other to form a large unit called a colony. As the colonies grow each polyp makes more cups that stack on top of the old cups. Corals can live for 10's to 1000's of years and produce huge colonies that are effectively stacks of limestone cups fused together. Coral growth builds coral colonies, and millions of colonies form huge reefs and structures including islands.

11. Coral Polyp
    a. Along the edge of the bag they have tentacles that allow them to catch food. Inside each of the tentacles are stinging cells called nematocysts. These stinging cells are like harpoons that shoot out and catch food floating by in the plankton. They explode out of the tentacle at 10K x's the force of gravity, more g-force than a shuttle lift off. It is the fastest mechanism in the animal kingdom. Once the harpoons are in the flesh of an unsuspecting prey, they release toxins to stun and kill the prey.
12. Coral Symbiosis
    a. Corals work together with algae (single celled plants) to get energy from photosynthesis. These single celled algae are called zooxanthellae or *Symbiodinium*. The zooxanthellae use the coral as habitat, a safe home. The zooxanthellae can be as dense as one million per cubic centimeter of coral tissue. Through this symbiosis corals can also get energy from photosynthesis, which means they thrive in clean, clear water. This photo is a close up of a coral polyp and the brown dots you see are individual zooxanthellae. This coral polyp is about the size of the tip of a pen.
13. Coral Symbiosis
    a. Zooxanthellae produce sugars and carbohydrates for the coral and the coral provides a safe home for the algae. This relationship where organisms of two different species benefit each other is a type of symbiosis called mutualism. This mutualism has allowed corals to grow in habitats where there is relatively little food as long as there is clear water to allow adequate light. The extra energy from their symbiosis (algae proved energy from photosynthesis) is critical for coral colonies to build their limestone skeletons. Because the energy from their algae is critical for growth anything that disrupts this symbiosis is very bad for the corals.
14. Clear Water
    a. Corals need clean clear water to grow. Sunlight has to reach the bottom of the ocean for corals to gain energy from their algae using photosynthesis.
15. Coral Killers-Sedimentation
    a. Local activities can change water quality and stress corals. Coastal development allows sediments to get into the ocean. Development (leveling building sites, filling in wetlands) and flood control (putting cement around streams) increases the amount of sediment transported into the ocean. Increased roads, parking lots, and other impermeable surfaces force rainwater into the ocean instead of soaking into the land. Storm drains often flow directly to the ocean, rinsing trash, oil and other waste found on roads into the oceans. During heavy rain storms sediment and other waste get flushed into the ocean, which makes the water cloudy and the debris can smother the coral as it falls out of the water.

16. Coral Killers-Overfishing
    a. Overfishing can disrupt the balance of reef ecology. Many fish eat algae that compete with corals. When the fish are removed it gives the algae a chance to grow and proliferate. Algae grow faster than corals, occupying important space and often out competing the corals.
17. Coral Killers-Disease
    a. Coral disease has become more widespread, occurs more frequently and is better documented in the last few decades. Disease often grows more rapidly and spreads more easily in the presence of excess nutrients. Nutrients come to reefs from over fertilization of crop fields and golf courses. Fertilizers are often rinsed off lawns and yards into storm drains. Sewage on many islands is not treated but it is released on the reefs (photo on the right) creating an influx of excess nutrients.
18. Coral Killers-Ocean Acidification
    a. As seawater absorbs more carbon dioxide the pH and alkalinity change. As seawater chemistry changes many of the calcifying organisms will find it more difficult to extract calcium carbonate out of seawater to make their skeletons. Over the long term coral skeletons will dissolve; however, it is important to know that the research for dissolving skeletons tests corals at very acidic pH values probably more extreme than those seen in the next 300 years.
19. Coral Killers-Ocean Acidification
    a. We are still studying the impacts of Ocean Acidification on coral communities. Preliminary studies show that some coral species can't grow and have reproductive failure in OA conditions. In natural CO_2 seeps in Papua New Guinea we see that some corals will survive OA conditions but other do not, suggesting that we will lose the diversity of corals on reefs and instead will be left with fewer coral species.
20. Coral Killers-Rising Temperatures
    a. Global climate change can also stress and kill corals. More carbon dioxide in the atmosphere increases the temperature of the atmosphere and the temperature of the sea surface (shallow zones of the ocean). Increased sea temperature causes bleaching which is a break down in symbiosis. Corals thrive at ocean temperatures between 26-27 °C (79-81 °F). This graph shows how sea surface temperatures from around the world compare to an average set between 1971-2000. You can see that temperatures have consistently been above average during the recent decades. Sea surface temperatures have been higher in the last 3 decades than at any other time since 1880.
21. Coral Killers-Bleaching
    a. Higher temperature means the algae start to release toxins instead of sugar, so the coral releases the algae from its tissues. An analogy is a tenant (the algae) stops paying rent to it's landlord (the coral) and gets kicked out of it's home. Once the algae are gone, the coral has a

white appearance and is said to be “bleached.” In this slide you can see how the same species of coral looks when it is bleached and healthy.

22. Coral Killers-Bleaching
    a. During bleaching photosynthesis in zooxanthellae stops working well. Instead of sugar the zooxanthellae make reactive oxygen species (superoxide radicles and hydrogen peroxide) that are toxic to the corals. Thus the corals kick the zooxanthellae out of its tissue much like you would evict a renter that destroyed your house.
23. Coral Killers-Bleaching
    a. In extreme cases whole reefs can be bleached. Bleaching can kill coral, but it depends on the species of coral and how long the temperature stress lasts. The coral can survive for a little while without algae (weeks to months), but if high temperatures persist the coral colonies will die.
24. Coral Killers-Bleaching
    a. Major bleaching events have been recorded in 1998 and 2005 both of which had El Nino weather patterns. This year (2014) is forecast to be another extreme El Nino year. Watch the popular press for stories of coral bleaching across the Pacific Ocean.
25. Interacting Stressors
    a. As coral bleaching is becoming more frequent and sever we are starting to see that this stressor combined with other local stressors (overfishing, competition with algae, water quality and pollution) can cause more stress and death than either stressor alone. We are just beginning to understand the complexity of how multiple stressors interact to harm natural ecosystems.
26. Recovering Reefs
    a. But there is hope. There are still coral reefs like this on the planet. High coral diversity and healthy colonies.
27. Recovering Reefs
    a. Healthy reefs provide homes for fish and food and tourism for people from many cultures. We should be doing all we can to preserve coral diversity and reefs on a local and global scale.
28. Things you can do to help
    a. In the face of all these threats, it is important to remember that we can save coral reefs. Coral and algae have a unique partnership that forms the basis of coral reef ecosystems, but for corals to survive, we need to be good partners as well. Remember that coral reef conservation begins on land, and we need to change some of our own activities in order to help. Here is a list of things we can do to protect coral reefs.