Notes for frames of the TOGA school resource

1 – Oysters in Chesapeake Bay - Skipjacks still exist, mostly owned by museums, and races are still held. They could only legally dredge while under sail. They had a "push boat" with a motor (seen hanging off the stern) in case they could not navigate by sail, but they could not dredge under power.

2 – An early drawing - Early accounts comment on the clarity of the water and that the bottom could easily be seen to depths of about ten feet. Visibility today in summer is mostly less than a foot. Oysters as long as one foot were common. Astronomical tide could be discussed.

3 – Water filtration - "Pseudofeces" can be seen to lower left of the oyster. Filter-feeders must get rid of suspended particles that have been rejected as unsuitable for food. The rejected particles "pseudofeces" are incorporated in mucus and expelled without having passed through the digestive tract. The large particles (aggregates of sediment and algae) settle to the bottom much faster than would otherwise happen. Note how the shell is being bored or bioeroded by organisms like sponges and worms. Also note the growth lines. The short (43 seconds) video showing filtration could be shown here: www.chesapeakebay.net/fieldguide/critter/eastern_oyster. There are other useful resources on the web site. The filtering video is also available at: www.youtube.com/watch?feature=player_embedded&v=1Zm-yMpHsaQ#!

4 – Pile of oyster shell - Lime is produced by "burning" calcium carbonate to produce calcium oxide or calcium hydroxide: $CaCO_3$ -> CaO + CO_2 and CaO + H_2O -> $Ca(OH)_2$. Calcium oxide and calcium hydroxide are used for cement. Describe oyster tongs – hand tongs and patent tongs.

5 – Oyster dredge - Bycatch describes organisms caught unintentionally and not utilized. Most are injured or killed. Dredges are notorious for uprooting and killing sea grass. In the past, many fisheries were overharvested or "fished-out" and then the fishers moved to a different place, or targeted a different organism. It continues to happen today, with tuna for example, but not in Chesapeake Bay.

6 – Oyster landings before 1935 - Shell was the only available material for roads because the transportation network did not yet exist to import gravel from the Piedmont. Watermen knew the shell should be returned to the water, but economics prevailed.

7 – Oyster landings 1935 to 1958 - If the trend between 1935 and 1958 is extrapolated to 2010, harvests might be nearly as high as was true at the beginning of the 20th century, presuming that harvests were regulated. The Piedmont is the geologic province west of the coastal plain. The "fall line" separates hard igneous and metamorphic rocks to the west from less consolidated sediments of the coastal plain to the east. Piedmont rocks caused rapids and water falls that prevented deep draft boats from venturing westward, hence the phrase "fall line."

8 – Oyster landings 1960 - Comment on the generic (*Crassostrea*) and specific (*virginica*) name. The introduced oyster was *Crassostrea gigas*, which did not grow well in the Bay. Another endemic disease, Dermo, affects oyster populations because so few oysters exist in the Bay, and those that do exist are weakened by MSX and perhaps other factors. Global warming is likely to favor the two oyster diseases, along with pathogens like Vibrio which can be toxic to humans.

9 – Oyster landings today - Repeat the fact that when Europeans arrived it only took a few days for oysters to filter a Chesapeake Bay-sized volume of water.

10 – Oyster reef - “Ecosystem” is the community of all living organisms (plants, animals and microbes) and the nonliving components of their environment. Point out fish, blue crab (lower right), sponge (orange clump at left edge). Oyster reefs provide habitat and sanctuary for many other organisms. Other organisms on the reef are also filter-feeders, like barnacles and sponges.

11 – Energy from the Sun - Be sure students know the chemical elements that go into the formulas, and the names for them. The equation is balanced – $6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$ with 6 carbon atoms, 12 hydrogen atoms and 18 oxygen atoms on both sides. Glucose is a sugar, but other organic compounds are produced by photosynthesis. There exist other ecosystems that derive their energy from chemical reactions, ultimately fueled by Earth’s internal heat – “black smokers” are an example.

12 – All living things need energy to live - Chlorophyll is green but there are also other pigments.

13 – Photosynthesis - Other compounds can be formed. Using glucose (a simple sugar) results in a convenient equation.

14 – Respiration - Respiration is the exact opposite of photosynthesis and “burning” is a good analogy.

15 – Cycle of life - Emphasize autotrophs as primary producers and heterotrophs as consumers. The “food web” contains primary consumers (like zooplankton), as well as secondary, tertiary, etc. consumers. The decomposers convert organic material back into inorganic compounds.

16 – Nutrients - In sea water most of the nitrogen is present in oxidized form, as nitrate (NO_3^-). Bottom sediment can contain nitrogen in reduced form, or ammonia (NH_3^+). Phosphorus is present as dissolved phosphate (PO_4^{-3}). Nitrogen is needed to synthesize organic compounds like amino acids and phosphorus is important in regulating energy transport in cells. The three numbers on a bag of fertilizer, e. g 10-10-10 are the %N, %P and %K (potassium). Potassium is abundant dissolved in sea water so it is not a limiting nutrient element in the sea.

17 – Phytplankton - Diatoms have skeletons made of silica. They can form geologic deposits called “diatomaceous earth” and are used for filtration, among other things. There are many other kinds of phytoplankton and each kind can grow exponentially (bloom) at different times during the growing season, especially in spring. Cyanobacteria or “blue-green algae” are another kind of phytoplankton commonly associated with over-fertilized water.

18 – Zooplankton - The picture of the “copepod” is really a krill, but think of them as tiny shrimp. Some of the zooplankton can also photosynthesize because they contain algal cells in their tissues.

19 – Nekton - Or really big like whales.

20 – Benthos - Fish like flounder feed on the bottom but can swim in the water column, so the boundaries between “nekton” and ”benthos” can be blurred. Also, many animals spend the early parts of their live cycle as plankton and then either settle on the bottom (like oysters) or live in the bottom sediments as adults.

21 – Decomposers - Ensure that students understand all the words – microbes, respire, organic material, ecosystem, primary productivity, etc. Biofilms are microbial “slime” that coats surfaces like oyster shell. Biofilms on your teeth cause cavities. Note the scale. Each small interval is 1 micron, or 1/1000 of a millimeter, so the total scale is 10 microns or 1/100 of a millimeter.

22 – Red tides - Harmful Algal Booms (HABs) is an acronym for this phenomenon.

23 – Oyster Life Cycle - Male oysters release sperm and female oysters release eggs. If fertilization occurs, the larvae (zooplankton) grow and feed on algae. When the larvae are ready to “set” or “strike” they develop an eye spot (eyed larva – upper right) and a foot, and become a pediveliger. Then they attach (“set” or “strike”) to a hard substrate and grow as sessile benthic organisms. Simultaneous spawning by many closely associated animals on reefs increases the likelihood of fertilization. Spat prefer to attach to clean substrate. Many shells show growth lines (shown on drawing at lower left). Show the 7 minute video "Spawning Oysters by Thermal Shock” (www.aces.edu/dept/fisheries/education/) here. It shows how broodstock are spawned and how the fertilized eggs develop into larvae up to the eyed larva stage. The fact that larvae must be fed by algae grown in the hatchery should be emphasized.

24 – Shell growth - Oysters calcify as the mantle deposits crystals of the mineral calcite (calcium carbonate or $CaCO_3$), both extending and thickening the shell. The process is not too different from the way we grow our bones and teeth. The tentacles of the mantle trap particles suspended in the water, add mucus, and transfer some of the particles to the mouth, where they are ingested, processed by the digestive system, and then excreted as feces. Particles not ingested are discarded

as pseudofeces. If available, paired shells could be passed around and discussed. A ligament at the umbo normally holds the shells open and they must be closed by the muscle, which leaves "muscle scars" inside both shells. A closed oyster is a live oyster. Many shells are bored or bioeroded on the outside by organisms like sponges and worms.

25 – Sterile oysters - Diploid – 2 chromosomes (normal, fertile), Tetraploid – 4 chromosomes by genetic manipulation in the laboratory, Triploid – 3 chromosomes (sterile). Why breed a sterile oyster?
Fertile oysters use energy to produce eggs and sperm in summer, so oyster meat is "watery" in the months with no "R" (May, June, July and August). Sterile animals put all their energy into growth and tissue so they are a more marketable product in summer. But they do not produce larvae.

26 – Oyster reefs as habitat - Emphasize the food web. If available, dried and/or preserved examples of reef organisms could be passed around and discussed. When Europeans arrived, oysters as long as a foot were common. Today, diseases kill the oysters long before they can grow that big.

27 – Simultaneous spawning - This sponge is releasing gametes and mucus into the water. For some species, the time of spawning can be predicted to within an hour or so each year. Simultaneous spawning makes fertilization more likely. Just as in a hatchery, a small sudden rise in temperature (thermal shock) can trigger spawning, but chemical compounds are also likely involved. There is an obvious evolutionary advantage if many oysters are in close proximity to each other on a reef rather than being dispersed and that is one reason oyster reefs are so important.

28 – Ecological services 1 - Sea grasses expand in years when there is low rainfall and therefore low runoff (and groundwater discharge) because fewer nutrients (nitrogen and phosphorus) are discharged into the Bay to grow phytoplankton. But the gains are negated and sea grass beds contract when nutrient input increases in wet years. The fact that sea grass beds can expand means that seeds are available and if the nutrient discharge could be kept at low levels, sea grass beds might expand permanently to the benefit of the entire ecosystem. Sea grass beds occupy only a few percent of the area they occupied at the time Europeans arrived. So two major ecosystems, oyster reefs and sea grass beds, have been nearly destroyed by humans and they will not recover until fertilizer discharge to the Bay is significantly reduced.

29 – Oysters do not remove nutrients - Be sure students understand all the words: pseudofeces, decomposer, respiration, phytoplankton, etc. The amount of nitrogen and phosphorus removed from the Bay ecosystem in the tissues of the oysters is trivial.

30 – Chesapeake Bay water quality - About half of Bay Nitrogen and Phosphorus pollution comes from inefficient crop fertilization. About 25% of Nitrogen and

Phosphorus pollution comes from the point source discharge from wastewater treatment plants. The remaining 25% comes from lawn fertilization, stormwater runoff and natural processes.

31 – Dead zone - In early summer, as the water warms, Chesapeake Bay develops stratification or layering, with warm low salinity water above colder higher salinity (denser) water. The deep dense water is out of contact with the atmosphere and it is too deep for photosynthesis so there is no source of dissolved oxygen. As oxygen is respired by animals, and especially by microbes, the water becomes hypoxic (low dissolved oxygen gas) and then anoxic (no dissolved oxygen gas) so that only some microbes can survive and there are no zooplankton, nekton or benthos. The dead zone is typically about 30 feet below the surface in mid summer and disappears in winter as the surface water cools and becomes more dense and as the wind stirs the water to the bottom. On the right side, oxygenated water near the surface that can support animal life is shown by the super-abundant plankton and the fish. The dead zone is below the fish. On the left side, benthic organisms and nekton can occupy the entire water column.

33 – Eyed larva - Point out the eye spot (top center). The larva is about 250 microns in size (1/4 mm) and is between 2 and 3 weeks old. Selective breeding is used to improve desirable characteristics of both plants and animals, including oysters, and works just like natural selection.

34 – Grow single oysters 1 - Water is being pumped up through the cylindrical silos and out through the "elbows" on the left side of each silo. Screens on the bottom of the silos prevent the oysters from falling through. Oysters are transferred to silos with coarser screens as they grow. Silos must be cleaned frequently so the entire process is labor intensive. Each silo contains tens of thousands of oysters, depending on their size.

35 - Grow single oysters 2 - There are many "multiples" or examples where more than one eyed larva has attached to a single piece of tiny shell (called microcultch). These will be broken up as the oysters grow and are sieved to separate the ones that have grown slowly from the larger ones that have grown faster. Oysters don't all grow at the same rate, as you can easily see, and that is one reason they must be sieved frequently.

36 - Grow single oysters 3 - The water is being moved by the black paddlewheel on the right. Note the electric hoist to lift the large silos out of the water for cleaning and sieving. Each silo might contain a million seed oysters and there are about a dozen silos. FLUPSY is an acronym for FLoating UPwelling SYstem.

37 - Grow single oysters 4 - Cages are best deployed where the bottom is hard and where there is active water flow to provide food and wash away the pseudofeces. Much larger cages can be used.

38 – Oyster gardens - Oyster gardeners buy seed oysters and grow them in floats or by hanging the oysters in cages from their piers. Many kinds of apparatus have been invented. Note all the barnacles on the Delano cage. When the top of the flip float becomes fouled, it is just flipped so the algae causing the fouling no longer get enough light to live. No matter what kinds of cages are used, they must be cleaned periodically because the fouling will reduce water circulation. Oysters grow fastest near the surface. The oyster gardening video can be shown here. The video http://www.youtube.com/watch?v=zpRzFTWghOE may also be useful.

39 – Spat on shell 1 – Shell is no longer very abundant and getting expensive. Bagging is labor-intensive.

40 – Spat on shell 2 - Continued circulation and aeration is important. This can only be done when the water temperature is within a few degrees of 85°F. Only about 20% of the eyed larvae actually “set” or “strike” and the remainder go overboard to become part of the zooplankton.

41 – Spat on shell 3 - Cow-nosed rays can considerably reduce the number of oysters recovered. Diploid oysters that are not harvested can breed, but many aquaculture operations use triploid animals because they are “meatier” in summer.

42 - Spat on shell 4 - The spat on the bottom two shells is probably a couple months old. The cluster at the top has probably grown for two summer seasons. Oysters do not grow in winter when water temperatures are lower than about 50 degrees F (10 degrees C).

43 – Predators - Cow-nosed rays are also called sting rays. Sharks have been over-fished largely for their fins because shark fin soup is an oriental delicacy. There are expanding efforts to develop a market for ray meat and to encourage recreational and commercial ray fishing. Shells can also be bored or bioeroded by organisms like sponges and worms, eventually turning them into sand. Shells can be destroyed in a few years today, much more rapidly than in the past, because biofilms develop rapidly in the nutrient-rich water and encourage the growth of boring and scraping organisms.

44 – Biofilms - The development of biofilms is one reason there is not much natural “strike” or “set” today and why “spat-on-shell” is more effective. Many people believe that any oyster shell that is disposed into the water, without spat attached, is a wasted resource. Biofilms encourage colonization by organisms like sponges and worms that bore or bioerode the shell, eventually destroying it. In addition, other organisms “scrape” the biofilms off the shells for food, eroding the shells at the same time.

45 – Reef restoration - The “inverted egg carton” morphology is an attempt to emulate the morphology of natural reefs. Only shell at the surface of the mound can

attract oyster strike. The shell within the mound is a wasted resource, and shell is getting scarce. Sanctuary reefs are also very susceptible to illegal harvesting.

46 – The future? - Hand tonging an oyster ground.