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CAN BACTERIA SAVE AN ESTUARY'S FOOD WEB?

Alice Tung[1*], Peggy W. Lehman[2*] and John Durand[1]

[1] *Center for Watershed Sciences - University of California, Davis, Davis, CA, United States*

[2] *Division of Integrated Science and Engineering, California Department of Water Resources, West Sacramento, CA, United States*

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Scientists in the San Francisco Estuary (Estuary) are trying to solve the puzzle of why many small native fishes are starving. Zooplankton are important food for small fish in the Estuary, but there are fewer zooplankton in the Estuary than there used to be. Why are zooplankton in such short supply? Possibly because they are hungry, too! Floating plant-like organisms called phytoplankton, the usual food for zooplankton, have disappeared from some areas of the Estuary. However, bacteria may be able to help with this food shortage. Bacteria in the water eat a carbon-containing substance called organic matter that is released from both living and dead organisms. As bacteria eat and grow, they stick together to make clumps of food big enough for zooplankton to eat. Since a lot of organic matter exists in the Estuary, these tiny bacteria may be able to save small native fishes by making food for zooplankton. In this article we will discuss what dissolved organic matter is and how bacteria may be an important puzzle piece for making fish food in the estuary.

THE SAN FRANCISCO ESTUARY FOOD WEB PUZZLE

The San Francisco Estuary (Estuary), in California, USA, is the largest estuary on the west coast of North America. The Estuary is formed by the Sacramento and San Joaquin rivers, which meet and flow westward through San Francisco Bay into the Pacific Ocean. Along the way, the fresh water from the rivers and the salty water from the ocean mix and form the San Francisco Estuary (Figure 1).

Scientists have studied the upper San Francisco Estuary since the 1960s, when the Estuary had many healthy native fish populations. In the 1980s, scientists began to notice that some native fish species were disappearing from the Estuary. They determined that many small fish were probably dying because they were running out of food. Like putting together a jigsaw puzzle, scientists pieced together the **food web** of the Estuary to understand what is needed to make these fishes healthy.

FOOD WEB

The map of "who eats whom" in an area. Food web maps help scientists describe connections between organisms and identify critical food pathways that need to be studied.

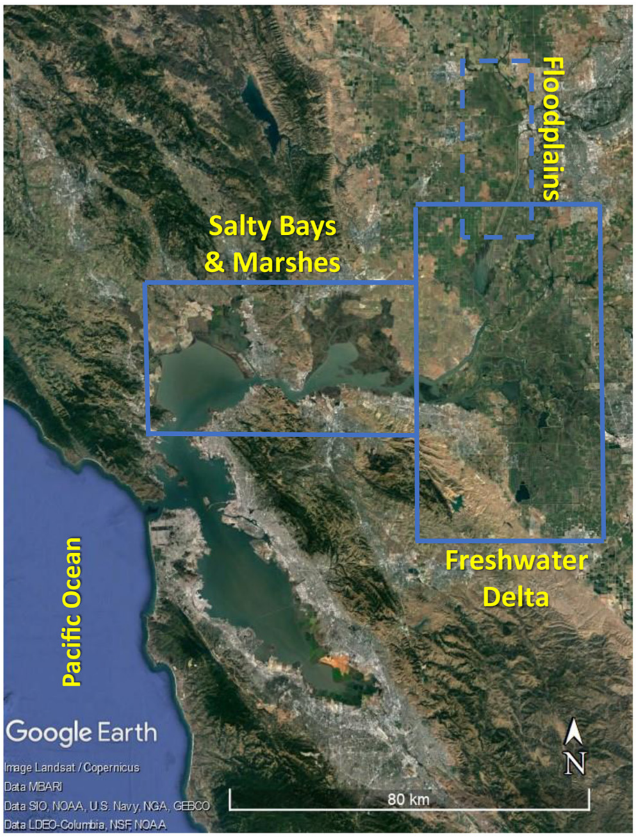

Figure 1

Figure 1

The upper San Francisco Estuary (boxed areas) showing its many ecosystems. The Estuary contains salty marine bays that form slightly salty marshes, freshwater rivers that meet to form a delta, and floodplains, which are lands that flood when river flow is high.

WHAT IS ORGANIC MATTER?

Have you ever heard the statement, "carbon is the building block of life"? That is because all living beings are made of **carbon**. Carbon is a very special element that easily combines with other elements to form what is called **organic matter**.

There are two types of organic matter: particulate and dissolved. Particulate organic matter includes plants and animals and is big enough for animals to see and eat. In the waters of the Estuary, particulate organic matter includes tiny floating plant-like organisms called **phytoplankton** and tiny animals called **zooplankton**. When you swim in the Estuary, you are an example of a large piece of particulate organic matter in the water!

The Estuary also contains carbon in the form of dissolved organic matter. This is organic matter in liquid form. Dissolved organic matter is too small for us to see and for animals to eat. It comes from dead plants and animals that release liquids as they decay. Dissolved organic matter also comes from living organisms that leak fluids. For example, phytoplankton cells leak fluids through their cell walls, and zooplankton release liquid waste.

WHERE DO BACTERIA FIT INTO THE FOOD WEB PUZZLE?

Bacteria are the only critters that can eat dissolved organic matter! As bacteria eat and grow, they stick together and form small clumps. These clumps of bacteria eventually become big enough as particular organic matter and can be eaten by small animals. Small clumps of bacteria are often eaten by organisms called "**bacterivores**," which can then be eaten by zooplankton. If the clumps of bacteria get really big, they can also be directly eaten by zooplankton.

The process that converts dissolved organic matter to particulate organic matter through the growth of bacteria is called the **microbial loop** (Figure 2). Without this highly important process, the carbon that is present in dissolved organic matter would be "lost" to the food web [1]!

THE UPPER SAN FRANCISCO ESTUARY IS LOW IN PARTICULATE ORGANIC MATTER

Particulate organic matter in the form of phytoplankton is the main food that supports the food web in the Estuary [2]. However, compared to most other estuaries, the upper San Francisco Estuary is low in particulate organic matter. Most of the organic matter in the Estuary is

CARBON

An element that is used to build organic matter. Carbon is considered the "building block of life."

ORGANIC MATTER

Carbon-containing matter from living organisms or recently living organism. Organic matter can be particulate (large enough for animals to eat) or dissolved (so small that only bacteria can eat it).

PHYTOPLANKTON

Microscopic, single-celled or colonial plant-like organisms that float in the water.

ZOOPLANKTON

Tiny organisms in the water that eat phytoplankton and other small organisms. Zooplankton are an excellent food for small fishes.

BACTERIVORES

Microscopic, single-celled organisms that use bacteria as a source of food. Bacterivores can be eaten by zooplankton, so they directly connect bacteria to the larger animals of the food web.

MICROBIAL LOOP

The process by which carbon from dissolved organic matter is transferred into the food web with the help of bacteria and bacterivores.

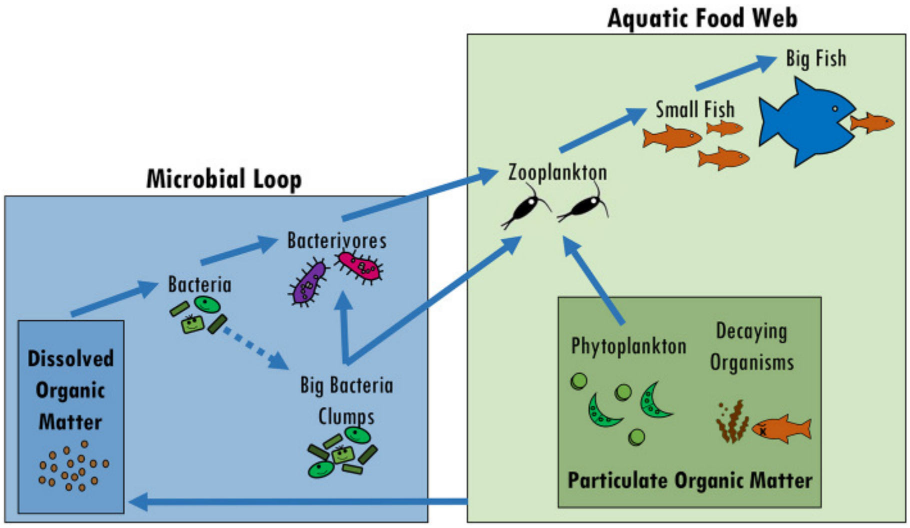

Figure 2

Figure 2

The link between the microbial loop and the aquatic food web in the San Francisco Estuary. Dissolved organic matter becomes particulate organic matter as bacteria eat it and grow to form clumps. Small clumps of organic matter are eaten by bacterivores and zooplankton eat both bacterivores and big clumps of organic matter. Zooplankton are then eaten by fish. Dissolved organic matter is leaked or excreted by zooplankton and fish, and the cycle, called the microbial loop, starts over. Blue arrows show the movement of organic matter from the microbial loop to the food web and back.

dissolved organic matter, which can only be taken up in the microbial loop [2].

Scientists have two explanations for the low amount of particulate organic matter in the Estuary. Firstly, there are not enough phytoplankton to support the food web. Even though the Estuary has plenty of nutrients for phytoplankton to eat and grow, they still grow slowly in the Estuary because the water is so muddy that it blocks light from entering the water. Without light, phytoplankton cannot grow fast enough to feed zooplankton [3]. Second, an invasive clam species, the overbite clam, entered the Estuary in 1986 [3, 4]. This clam filters phytoplankton out of the water for its food, which lowered the amount of phytoplankton available for zooplankton between the 1970's (Figure 3A) and the 1980's (Figure 3B). Between the muddy water and the invasive clams, not enough phytoplankton exists anymore to feed zooplankton in many parts of the Estuary.

CAN BACTERIA SAVE THE FOOD WEB?

Initially, the microbial loop was thought to be unimportant to the food web in the upper Estuary [2]. However, recent research suggests the type of zooplankton in the food web have changed, and new species are more able to use bacteria as food. A new species of small zooplankton called *Limnoithona* is now very common in the Estuary [5]. *Limnoithona* may be thriving because it can eat the tiny bacterivores and clumps of bacteria produced by the microbial loop! However, scientists are not sure whether *Limnoithona* will be good food for small fish in the Estuary.

In a study conducted in the floodplains, researchers found that zooplankton grew well when decaying organic matter was present in

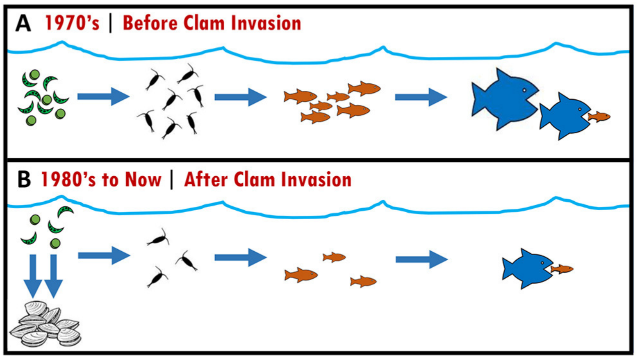

Figure 3

Figure 3

Invasion by the overbite clam changed the food web in the San Francisco Estuary. The arrows show "who eats whom" in the Estuary. **(A)** Before the invasion of the overbite clam, the zooplankton ate phytoplankton. Small native fishes were abundant because they had lots of zooplankton to eat. **(B)** After the overbite clam arrived, phytoplankton decreased because the overbite clam ate them. This means there was less food for zooplankton which affected food for fish.

the water [6]. This decaying organic matter helped grow 53 times more zooplankton compared to those in the nearby river. In fact, young fish in the floodplain had so much zooplankton to eat that they grew five times faster than fish in the river! The ability for the floodplain to grow a lot of fish food, possibly by using the microbial loop, may be a new and key piece to the food web puzzle.

SOLVING THE PUZZLE TO BRING FISH FOOD BACK

We hope that future studies will help us determine how the microbial loop can contribute to bringing fish food back to the parts of the Estuary where fish are starving. Can you think of ways that the microbial loop might be able to help small native fishes in the upper San Francisco Estuary? Maybe a small native zooplankton species can thrive on bacteria from the microbial loop and can also be a great fish food. Maybe floodplains can be flooded on purpose to create the dissolved organic matter needed to grow bacteria and feed fish [7]. Maybe it is possible to transport the fish food grown on floodplains to areas in the Estuary where food is harder for fish to find. Much work remains to be done, but scientists are hopeful that these pieces of the puzzle will fit together to help them bring fish food back to the upper Estuary!

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We are the best school in the world, because we are the tallest and the cleverest, and we have the best teachers. But specifically we are the best class of the school because we have a lot of different type of people and we are very funny. We love science because we have a very good teacher.

AUTHORS

ALICE TUNG

I am a Ph.D., student of ecology at the University of California—Davis. I study how well-phytoplankton grow in the upper San Francisco Estuary. I am especially interested in researching how salty wetlands that are managed for duck food in Suisun Marsh may also contribute to fish food. On my free time, I love making desserts—dark chocolate mousse and French macarons are my specialty! *amatung@ucdavis.edu

PEGGY W. LEHMAN

I am a Ph.D., ecologist with a specialty in phytoplankton and currently work as a senior scientist for the State of California, USA. My research includes the growth, causes, and ecosystem impacts of the cyanobacterium *Microcystis* which forms toxic blooms in the freshwater reaches of San Francisco Estuary. I also study the phytoplankton in rivers and wetlands within the Estuary in response to environmental conditions, including climate change. In my free time, I enjoy watching changes in phytoplankton blooms as I kayak through rivers and lakes near home. *Peggy.Lehman@water.ca.gov. To find out more about my work see orcid.org/0000-0001-9556-0542.

JOHN DURAND

I study the ecology of food webs and fish in estuaries. I am particularly interested in how restored and managed wetlands create food and habitat for fishes and other animals, and the effects of climate change on these habitats. I got interested in wetlands and estuaries because I spent a lot of time kayaking in them, and I had a lot of questions that eventually led me to get a Ph.D., in ecology at the University of California, Davis, where I still work as a research scientist.