Aqua- Pop-Culture:

Module on Domestication and Broodstock Development

Grade Level:
7-12

Subject Area:
Life Sciences (Biology, Ecology, Environmental Sciences), Aquaculture, Agriculture

Time:
3-50 minute periods:
Day 1-PowerPoint presentation
Day 2-experiment
Day 3-Follow-up/Conclusion

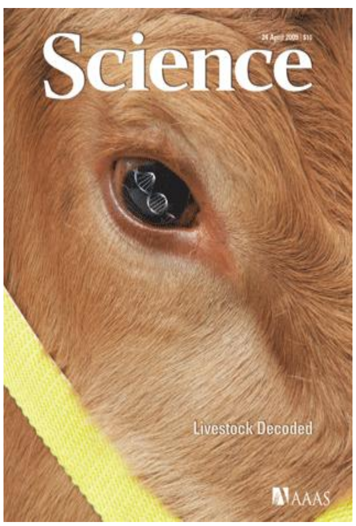
Student Performance Standards (Sunshine State Standards):
11.02 List and describe the physiology of aquatic animals (LA.910.1.6.1, 2, 3, 4, 5; SC.912.L. 18. 7, 8, 9).
11.08 List and describe important characteristics in choosing a species (SC.912.E.6.4; SC.912.E.7.4; SC.912.L.14.3, 4, 6, 7, 8; MA.912.A.1.1, 2, 4, 6; MA.912.G.1.1, 2, 4; MA.912.S.3.1, 2)
13.02 Explain how changes in water affect aquatic life (LA.910.1.6.1, 2, 3, 4, 5; SC.912.L.17.2, 3, 7, 10).
14.01 Identify factors to consider in determining whether to grow an aquaculture species (LA.910.1.6.1, 2, 3, 4, 5; MA.912.G.2.5; MA.912.G8.3, 6; SC.7.L.17.3).

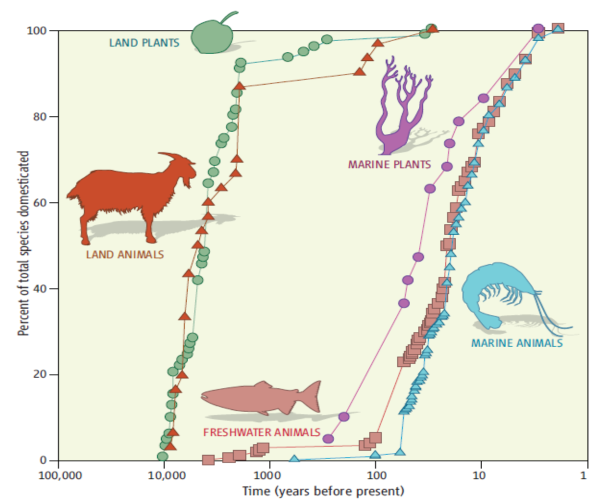
Objectives: Students will be able to:
1. Identify and use qualitative and quantitative observations.
2. Apply measuring skills.
3. Compare and contrast results from lab experiments.
4. Discuss experiment results and relate findings to real-world topics (in this case trait selection).
5. Describe trait selection within their peer groups.

Abstract:
This module explores the concepts and science behind domestication of species in aquaculture. Students will perform a lab that relates domestication of an everyday product, popcorn, to aquaculture. Popcorn is made out of corn kernels, corn or maize is one of the oldest known domesticated species so it serves as an excellent model that demonstrates the processes of domestication. The purpose of this lab is to introduce topics within domestication and have students gain an understanding of the ideas and concepts behind trait selection in popcorn. Students will compare the

similarities of selecting traits in popcorn versus those found in aquaculture domestication of species.

Interest Approach:
The following are two examples from recent articles in the journal Science, a premier science publication. This can be used to grab the students' interests that species domestication in ALL animals is a very relevant science topic. The successful cultivation of any organism depends on their domestication. Aquaculture is emerging as a revolution in agriculture of global importance to humankind. In contrast to land animals and plants where domestication of most species occurred thousands of years ago, the domestication of aquatic species is just happening. The field of aquaculture offers a unique and exciting area for exploration into the science and practice of domestication involving disciplines such as genetics, behavior, basic biology, and new product development.
http://www.sciencemag.org/content/vol324/issue5926/cover.dtl





Land versus water. Most land species were domesticated earlier than aquatic species, but in the past 100 years, many more aquatic species than land species have been domesticated (*6*).

Student Materials:
1. Popcorn Varieties- provided by teacher
2. Digital Scale
3. String
4. Ruler
5. Small plastic cups
6. Gloves
7. Data sheet

Teacher Materials:

Material	*Store*	*Estimated Cost*
Air-popper	Wal-Mart	$20
Popcorn varieties- store and heirloom *NO microwaveable versions*	www.popcornlovers.com Fireworks popcorn variety pack 	$11
Digital Scale/Triple Beam Balance	Wal-Mart/Carolina Biological	$20 and up/$90 and up
String	Any hardware store	$2 and up
Ruler	NA	NA
Small plastic cups	NA	NA
Gloves	NA	NA

Student Instructions:

1. Put name and record data on your provided data sheet.
2. Put a specific number of kernels (ex. 20) into a container and weigh the mass of the popcorn, in grams. You must weigh the empty container before doing this, record this number, and subtract it from the overall weight to obtain the actual mass of the popcorn or zero the digital scale.
3. Record the number of kernels and mass before popping.
4. Describe the color of each kind of popcorn kernel.
5. At this time, the teacher will use an air popper or microwavable popcorn container (not microwave popcorn), to pop the popcorn.
6. When the popcorn is done popping weigh the sample of kernels again. Remember to keep separate records based on each variety.
7. Count the number of unpopped kernels, which are called "old maids" and record them.
8. Measure the diameter of several popped kernels with a string, in millimeters, and record.
9. With teacher permission taste one kernel of each variety and describe the taste.

Teacher Instructions:

Preparations:

1. Purchase several popcorn varieties for comparison. Vary the color and kernel sizes. Try to get popcorn labeled heirloom and buy plain popular brand from the local grocery story (*NOT microwaveable*).
2. Set up small group stations with the different varieties in individual cups and gloves for handling.
3. Explain the concept of how popcorn pops:
   a. popcorn contains a small amount of water that expands and creates steam when heated
   b. the pressure breaks the hull, turning the kernel inside out and allowing steam to escape
   c. to achieve utmost popability the moisture content of popcorn should be from 13%-14.5% (13.5% is considered ideal)
   d. moisture content over or under these percentages greatly reduces popability and could result in more unpopped kernels
4. Have students predict how different kernels/varieties will result in different popping results**.**

*Activity***:**
1. Supervise students.
2. Popping the corn in the air-popper or microwaveable popcorn bowl.

*Post work/Clean-up***:**
1. Clean up and replenish popcorn kernels per group.
2. Place new handling gloves at each station.

Anticipated Results:
1. Teacher should expect the students to understand how popcorn can differ for each variety in size, shape, weight, and taste (figures 1 & 2).


Figure 1: Various varieties of popcorn and underneath them the resulting popped kernels. Note the changes in size of the kernels and the resulting size and color of the popper kernels. Students can compare and make measurements on each variety.

Figure 2: Showing the various color variations and sizes of popcorn varieties and the subsequent popped versions as they differ in size, shape, and color.

2. This should be linked to concepts in the domestication of fish species.
3. Student worksheet demonstration:

Type of Popcorn	Kernel #	Kernel Color	Kernel Size Before Pop	Kernel Size After Pop	Kernel Weights Before Pop	Kernel Weights After Pop	Kernels # NOT Popped "Old Maids"	Description of Taste and texture: Sweet, nutty, salty, soft
Midnight Popcorn	25	Blue/Black	8mm	46mm	2.58 g	3.4	5	Harder, Nutty, slight after-taste
Baby Yellow	25	Yellow	7mm	33mm	1.14 g	1.6	10	Soft, sweet

Support Materials:

1. Module Quick Guide with Outlined National and State Science Standards
2. Teacher Background for Aqua, Pop, Culture
3. Key Vocabulary Sheet
4. Student Data sheet for Activity
5. Student Lab Questions
6. Teacher Key Lab Questions
7. Article about Domestication from Science
8. Pictures of Domesticated Fish Example as compared to popcorn.
9. PowerPoint on Domestication and Aquaculture

Explanation of Concepts:

Science concepts demonstrated in this lab are related to heritability, selection of traits, and domestication of species. See background support materials for more information on science concepts covered.

 **Support Materials** 

Module Quick Guide with Outlined National and State Science Standards

AQUA-POP-CULTURE

This module explores the concepts and science behind domestication of species in aquaculture. Students will perform a lab that relates domestication of an everyday product, popcorn, to aquaculture. Popcorn is made out of corn kernels and corn is one of the oldest known domesticated species of plant, so it serves as an excellent model that can demonstrate the processes of domestication.

Title for Lesson Plan: Aqua, Pop, Culture
Grade Levels K-12: 6 -12
Subject Areas: Life Sciences (Biology, Ecology, Environmental science) Aquaculture, Agriculture
Topics: Domestication, Brood stock Selection, Artificial Selection
Skills: Reading, Research, Synthesis
Learning Styles: Visual, Kinesthetic, Auditory
Indoors or Outdoors: Indoor Lab
Estimated duration of activity: Three 50 minute periods, one day for PowerPoint, one for experiment, one day for follow-up and conclusion
Group size: 4 Students per group
Florida Science Standards:
SC.912.L.15.4 , SC.912.L.15.9 , SC.912.L.15.13 , SC.912.L.15.14 , SC.912.L.15.15
SC.912.L.15.Pa.d , SC.912.L.16.1, SC.912.L.16.2
National Science Standards: Content standard F: Personal and Community Health; Content Standard C: The interdependence of organisms.

Module Learning Objectives

1. Students will conduct an experiment exploring the differences in traits of popcorn for different varieties.
2. Students will measure and weigh the size of the kernels popped and unpopped.
3. Students will analyze the results and compare the different varieties of popcorn.
4. Students will discuss the results of the popcorn experiment and relate the different traits found to selection of traits in species.
5. Students will describe how the popcorn experiment to domestication practices through questions and discussion.

Teacher's Guide
AQUA, POP, CULTURE

1. Background

Fishing is a mode of hunting and gathering. Aquaculture is a mode of agriculture. The advent of modern agriculture was brought about thru the process of domestication. A slow and detailed process of adaptation of life forms (e.g., animal or plant species) to an existence intimately and beneficially associated to human beings. Many domesticated species are specifically adapted to the artificial conditions provided by their caretakers, hence the term derived from the Latin 'domesticus' or belonging to the house.

No definitive records are available to establish the beginnings of aquaculture, however it is believed to have origins dating as far as 4000 years ago; first written records began to appear about 2500 years ago. Aquaculture practices were suspected to developed in China, and spread to the Indian subcontinent and Mediterranean regions. The first practices of fish farming in the United States are known from ancient fishpond remains in Hawaii dating back some 1000 years. Between the 1700s' and 1900', easier means of communication and development of better agricultural methods facilitated the expansion of aquaculture practices worldwide.

Although humans have tried to domesticate many types of aquatic species, few have actually been domesticated. For more than a thousand years, first fish to be domesticated were the carps in Asia. Selective breeding of different color and body shape mutations in a species of carp also developed to what is known today as goldfish (*Carassius auratus*). The common carp (*Cyprinus carpio*) also was developed into colorful varieties of nishikiKOI (or simply known as koi). Avid hobbyists also have domesticated several varieties of ornamental fish, particularly the livebearing fishes of the family Poeciliidae, such as guppies, mollies, platies, and swordtails. Species considered domesticated include the common carp (*Cyprinus carpio*), trout (*Oncorhynchus mykiss*), Atlantic salmon (*Salmo salar*), channel catfish (*Ictalurus punctatus*), the oysters (*Crassostrea virginica* and *C. gigas*), some species of clams (e.g., *Mercenaria mercenaria*) and some crustacean species like freshwater prawns (*Macrobrachium rosenbergii*); some also consider hybrids of the genus *Tilapia* domesticated.

Together fish, molluscs, and crustaceans comprise hundreds of edible species that are still harvested today from the wild. Several hundred other species are harvested for multiple other uses from cosmetics to medicinal products. Such availability from wild sources has deterred long-term interests on their domestication. Most of our knowledge today on fish genetics has been learned through keen observations by fish hobbyists. In addition, only a few laboratories around the world have established programs for the study of aquatic genetic resources. Most importantly, only a few traits like egg size, and age at maturity have been determined to be heritable traits in aquatic species.

To achieve domestication, the desirable traits are first identified, such traits must be heritable, and the controlled breeding, completion or 'closing' the life cycle of the organism must be accomplished. Assisting in the domestication process is the species hardiness, and ease of care. Selection of the parent stock or brood stock, therefore, is the first step in the domestication process.

Since most of the species used today in aquaculture are of wild origin, the brood stock is mainly collected from the wild or simply held for short periods of time in captivity. Selection and mating systems are mostly not existent. Individual brood stock is selected primarily by visual examination of external morphological characteristics to determine their sex and stage of maturity.

Depending on the species, matured brood stock are induced to spawn or release their gametes by application of reproductive hormones or stimulating their reproductive behavior by providing them with some type of substrate to which females can lay their eggs.

Only a few of the species that are currently under cultivation have been able to be ‘conditioned for breeding’ or reach sexual maturity to successfully complete their ‘life-cycle’. Hence the process of domestication in most aquaculture species is in its beginning stages. Unless adult fish are successfully conditioned for breeding in captivity, spawned successfully, and larvae raised past their first-feeding, such matters will remain the principal obstacles for the domestication of aquatic species.

How do we breed and propagate aquatic organisms?

First we consider:

1. Selection of suitable species traits
    a. Availability, suitability for culture, ease of breeding
    b. Socio-economic considerations
2. Selection of suitable broodstock
    a. What are the heritable traits (e.g. egg size, growth rate, behavior, body form, coloration)

Then we consider:

1. Conditioning for breeding
    a. Temperature, water chemistry, photoperiod
    b. Dietary requirements
2. Breeding (Ties back to selection of suitable broodstock)
    a. Temperature, water chemistry, induced spawning
    b. Embryo and larval survival
3. Recuperation of the fish
4. Senescence (Ties back to conditioning for breeding)

Figure 1: A generalized guideline to the major factors involved in the breeding of fishes.

Genetics, Heredity, and Domestication:

Genetics is the branch of biology concerned with the mechanisms of heredity or the passage of a set of biological characteristics or qualities of parents to offspring, from one generation to the next. The foundations of modern genetics are often attributed to Gregor Mendel, performing inheritance experiments of particular traits in pea plants (Mendel was an Augustinian monk, born in a town now in the Czech Republic, then part of the Austrian empire). Mendel's works provided the first insights by which heredity operates (Law of Segregation and Independent Assortment) and that heredity information was made up of discrete fundamental units, which we now know are genes contained in the chromosomes inside the cell nucleus. Since chance determines which gametes (carrying the genes) will unite during fertilization, the outcomes of heredity are linked and studied together with the principles of statistical probabilities. The Punnett square (named after noted geneticist R. C. Punnett), described in most biology educational materials, is also used to help visualize and understand the workings of heredity. The basic principles of inheritance are now known to be similar in most species studied.

The domestication process is shaped by natural selection and guided by direct or deliberate human intervention: species are selected and bred for many generations under controlled conditions to obtain a particular characteristic or set of desirable traits.

The basis of the domestication process is that genetic material of a population is changed from one generation to the next. Domestication is achieved when the desirable traits are passed on from generation to generation; thru controlled reproduction such traits are made more common over successive generations.

While the selection of most domestic species is deliberate, some domestication occurs inadvertently and may have deleterious ramifications. Unfortunately, numerous introductions of freshwater and marine fishes, as well as invertebrates have been established around the world. Many of these species have great plasticity to adapt and colonize disturbed habitats. Through natural selection fishes are transformed into invasive or nuisance species, difficult to control. Afterwards they may become recognized as usable resources or simply tolerated and as such become unconsciously domesticated. The presence of live-bearing fishes (e.g., guppies), or striped bass, American shad, as well as the green mussel, in many natural bodies of water to which they are not native, and the frequent crossing and backcrossing (i.e., of escapees), influence the genetic composition of the parent stock and closely related species.

Less obvious are the unconscious effects us humans may have on not so apparent microorganisms such as free-living protozoas (e.g., dinoflagellates, amoebas, and paramecia) or those microorganisms that have tight symbiotic relationships with their host. Protozoa are an important component of the plankton community in open waters and together with algae form the base of the aquatic food chain. Protozoa also play an important role in wastewater treatment processes; only a few aquatic protozoa are pathogenic.

Classical examples of terrestrial protozoan symbionts are the termite flagellates, and rumen ciliates. In aquatic ecosystems, symbiotic protozoa associations are documented with algae and molluscs. Humans can easily affect and alter such symbiotic relationships by water pollution, poor sewage disposal, and utilizing non-target disease control methods. Conversely these symbiotic relationships can be exploited. For example, since many aquatic protozoa play an important role in the aquatic food web their culture and domestication is advantageous for the feeding of larvae of many difficult to feed aquaculture species.

All major types of life forms or species have been domesticated, from simple bacteria, protozoa, fungi, algae, to the animal and plants we are most familiar with. Species have been domesticated for different types of products such as for direct food consumption (e.g., livestock or farm animals for meat and milk, bees for honey, cereals or grains, legumes, vegetables, herbs, spices, fruits), clothing (e.g., cotton and other fiber plants, silk, wool), transportation or work (e.g., horse, donkey, water buffalo, llama), and companionship, pleasure, or ornamental purposes (e.g., cats, dogs, aquarium fishes, houseplants, cut flowers, garden and landscaping plants, pearls).

Other organisms such as bacteria have been domesticated (e.g., for preparing foods like cheese, yogurt, sour cream), yeasts (e.g., for baking, brewing and winemaking). Bacteria, fungi, and viruses also have been domesticated for the production of medicines, and use in scientific research. Species like elephants, gazelles, vicuñas, macaques, cormorants, and numerous parrots that are caught wild, tamed or trained are not domesticated.

In contrast to terrestrial species, only a few fish have been successfully domesticated as food source, such as carp, trout, salmon, channel catfish, and tilapia. Most domestic species of fish, like goldfish, have been domesticated for display in aquariums, as fish keeping is one of the most popular of hobbies worldwide. Like goldfish, live-bearing aquarium fish (members of the family Poeciliidae) such as guppies, mollies, platies, and swordtails have been domesticated into hundreds of varieties.

Popcorn is an ideal species for study of domestication since maize (*Zea mays*) has a long history of cultivation and use with humans; corn or maize is the most widely grown crop in the Americas, over 300 million metric tons annually in the United States alone. Popcorn was in everything from Aztec Indian ceremonies to use in the Peruvian Indian culture. It is even believed that the first use of cultivated maize or corn was for popping. Aztecs used popcorn not only for decoration, but also in ceremonies.

Breeding popcorn has been accomplished using different techniques ranging from simply selecting plants with desirable characteristics, similar to Mendel's selction experiments with pea plants, to the modern use of molecular techniques. Popcorn can come in many varieties, shapes, colors, sizes, and natural flavors. This type of corn can be an important tool when used to teach students about the processes of domestication and selections.

Although in its infancy, the selection, mating systems, development of breeds in fishes follow the same principles as those utilized for popcorn producing maize plants. At the moment, however, genetic manipulation may not replace the conventional methods in fish breeding programs as is occurring with plants. Current research in fish genetics and breed development focuses: identifying heritable traits and improving important quality traits such as feed conversion efficiency, growth rate, and carcass yield. Develop quantitative genetic models to understand wide range of genetic variations in cultivated fish populations, principally salmonid fish; exploration of molecular markers to facilitate identification and selection of the quality traits mentioned above.

References:

http://www.popcorn.org/index.cfm

Popcorn Production and Marketing. 1985. K. E. Ziegler, R. B. Ashman, G. M. White, and D. S. Wysong. National Corn Handbook, NCH-5, Purdue University, West Lafayette, Indiana.

Popcorn. 1987. L. W. Rooney and S. O. Serna-Saldivar, in Corn: Chemistry and Technology, Edited by S. A. Watson and P. E. Ramsted, American Association of Cereal Chemists. p. 420-421.

Key Vocabulary Sheet

Domestication: To train or adapt a plant or animal to live in a human environment making it fit for cultivation. This can be done by having humans intervene in the breeding of plants or animals and selecting traits that are of use to the human.

Trait: A feature that is an identifying characteristic, habit, or trend. It can be a genetically determined characteristic such as an aspect of the phenotype or genotype. Many times the characteristic is heritable and can be passed from generation to generation such as more muscle, greater size, greater fecundity, coloring, and even temperament.

Species: A group of living things that are so closely related that they can breed with one another and produce offspring that is fertile or can breed as well.

Phenotype: The observable characteristics or traits of organisms.

Genotype: The genetic makeup of an organism; all of the genes that an organism has.

Selective breeding: The process of breeding plants and animals with specific traits to produce offspring that have these traits.

Breeding: The process of producing offspring through natural or artificial means. The act of propagation from which growth and development of new individuals occur.

Pedigree: A chart that shows family relationships, including two or more generations.

Breed: a group of domestic animals that are of the same species and have a homogenous appearance, behavior, characteristics that distinguish them from others of the same species. Examples include dog breeds, while all or in the genus species of *Canus familiaris* Pembrooke Welsh Corgis are very different from Great Danes. The same can be true for the many varieties of Koi in fish.

Broodstock: This is a term used in aquaculture in which a sexually mature individuals are selected for breeding purposes and may be kept separate from the general population in a farm. These fish are used to propagate the next generations of fish. They may be selected for certain traits.

Student Data Sheet for Activity

Name: ______________________________ Date: ______________________

Observation Sheet

Popcorn Type	Kernel #	Kernel Color	Kernel Size Before Pop	Kernel Size After Pop	Kernel Weight Before Pop	Kernel Weight After Pop	Kernel # NOT Popped "Old Maids"	Description of Taste and texture: sweet, nutty, salty, soft, hard.

Student Lab Questions

Name: ______________________________ Date: _______________________

1. What is domestication?

2. How did each variety of popcorn differ?

3. Why would we select for different traits in popcorn?

4. How might a farmer do to select for traits in crops like popcorn?

5. How might this selection process be similar or different for animals?

6. Using the ideas found in your popcorn lab, what traits would you select for when breeding and domesticating fish?

Teacher Key
Lab Questions

1. What is domestication?

A slow and detailed process of adaptation of life forms (e.g., animal or plant species) to an existence intimately and beneficially associated to human beings. Many domesticated species are specifically adapted to the artificial conditions provided by their caretakers, hence the term derived from the Latin 'domesticus' or belonging to the house.

2. How did each variety of popcorn differ?

Various answers, should describe the observed differences in size, color, shape, and taste.

3. Why would we select for different traits in popcorn?

Consumers may choose to have popcorn that has a certain taste like sweetness or texture such as being soft or crunchy. Consumers also want popcorn that pops and does not leave many "old maids" or unpopped kernels. This might lead to the producers selecting for traits that lead to a sweet corn kernel when popped

4. How might a farmer do to select for traits in crops like popcorn?

The farmer may farmer may only cross or breed the individuals that have the selected traits they want. For example, he might select for size of the kernel in corn and only cross breed individuals that are large. Or they might select for taste and only breed corn that has a high sugar content.

5. How might this selection process be similar or different for animals?

The selection process might be similar for the traits that you select for such as size, shape, color, or taste. However, animals might have more traits that are proved worthy for selection like temperament. When working with animals farmers might breed the individuals that are the easiest to manage and create offspring with more agreeable temperaments. Animal domestication might differ from plant in that breeding for certain traits may not be as easy for production of the desired trait in offspring and artificial insemination methods may have to be used. Also with animals the element of time becomes a factor since you need to wait until the animal is mature and factor in the time for the gestation period of the young.

6. Using the ideas found in your popcorn lab, what traits would you select for when breeding and domesticating fish?

Fish might be selected for in their size, shape, colors, and texture. Fish in the ornamental fish industry are often specifically breed for certain color traits they have such as the Koi which have many varieties and color compositions.

Article about Domestication from Science

ECOLOGY

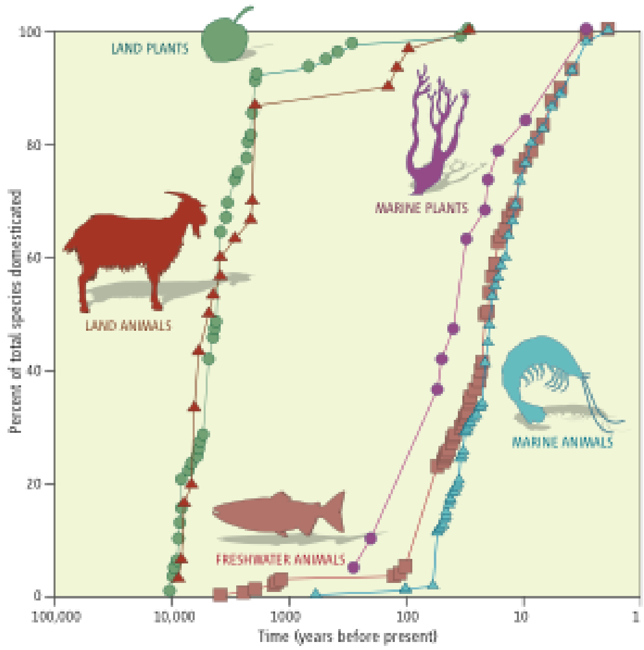
Rapid Domestication of Marine Species

Domestication has had higher success rates in the sea relative to those seen in the long history of land species' domestication. The rise of aquaculture has global consequences.

Carlos M. Duarte, Núria Marbá, Marianne Holmer

About 11,000 years ago, humans began to domesticate plants and animals (*1–3*). In the next 9000 years, hundreds of land species and a few aquatic species were domesticated. Since then, however, few land species have been domesticated. In contrast, the domestication of aquatic—particularly marine—species has grown exponentially. Aquaculture is emerging as a revolution in agriculture of global importance to humankind.

Domestication of wild species to produce food means that the breeding, care, and feeding of organisms are controlled by humans (*4*). By 2000 years ago, an estimated 90% of the species presently cultivated on land had been domesticated. Since the industrial revolution, the increase in the numbers of domesticated land plant and animal species has been modest (~3%) (see the figure).



Land versus water. Most land species were domesticated earlier than aquatic species, but in the past 100 years, many more aquatic species than land species have been domesticated (*6*).

In contrast, the rise of aquaculture is a contemporary phenomenon (*5*). About 430 (97%) of the aquatic species presently in culture (see the table) have been domesticated since the start of the 20th century, and an estimated 106 aquatic species have been domesticated over the past decade (see the figure) (*6*). The number of aquatic species domesticated is still rising rapidly (see the figure) (*6*). Even allowing that the rates for early domesticates are estimates, aquatic domestication rates are ~100 times as fast as the rates of domestication of plant and animal species on land over the period when domestication was fastest (see the table) (*6*). Despite a vastly longer history, the domestication of land species has been less successful than that of marine species (*7*), particularly for animals: 0.08% of known land plant species and 0.0002% of known land animal species have been domesticated (*7*), compared with 0.17% of known marine plant species and 0.13% of known marine animal species. Effective genetic improvement programs for many aquaculture species (*8*) should be facilitated by their huge reproductive output and short generation times compared to those of domesticated land animals.

There are several reasons for this contrast between the success in the domestication of land and marine animal species. First, land domestication has drawn largely from mammals and birds, with few invertebrates (such as bees and snails) domesticated. In contrast, a diverse array of marine taxa—including mollusks, crustaceans, vertebrates, echinoderms, jellyfish, and worms—have been domesticated (*9*, *10*). Many more wild marine species are used as food [more than 3000 marine species compared to fewer than 200 land species (*9*, *11*, *12*)], providing further scope for future domestication.

Second, the greater diversity of life forms in the ocean compared to those on land provides a broader range of opportunities for domestication. The limited success in domesticating land animal species has been attributed to the paucity of suitable species: Many land plants are poisonous or toxic to humans, and many land animal species have slow growth and long life cycles, specialized diets, or adverse behavioral traits (*3*).

Third, aided by the rapid spread of technical and scientific knowledge, domestication of aquatic species is developing globally, whereas land species were domesticated in just a few regions (*1–3*). A similar global effort to domesticate additional land animal species is precluded by the paucity of candidate species and the lack of market demand.

The domestication of an aquatic species typically involves about a decade of scientific research (*13*). Current success in the domestication of aquatic species results from the 20th-century rise of knowledge on the basic biology of aquatic species and the lessons learned from past success and failure. The domestication of aquatic species also involves fewer risks than that of land animals, which took a large toll in human lives through diseases transferred from herds (*3*); no human pathogens of comparable virulence have yet emerged from aquaculture.

The stagnation in the world's fisheries and overexploitation of 20 to 30% of marine fish species (*11*) have provided additional impetus to domesticate marine species, just as overexploitation of land animals provided the impetus for the early domestication of land species (*2*). Aquaculture production has been growing at rates of ~7 to 8% per year (*5*), compensating

C. M. Duarte and N. Marbá are at IMEDEA (CSIC-UIB), Instituto Mediterráneo de Estudios Avanzados, 07190 Esporles, Mallorca, Spain. E-mail: carlosduarte@imedea.uib.es M. Holmer is in the Institute of Biology, University of Southern Denmark, 5230 Odense M, Denmark.

for the stagnation of fisheries, and is likely to become the main source of marine food for humans as demands continue to grow.

The broad range of domesticated marine species helps to integrate the production across trophic levels, thereby maximizing output while decreasing environmental impact (*14*). It also increases the range of marine habitats where aquaculture can be conducted, and diversifies food sources and generates a wide range of market prices for aquaculture products. However, aquaculture development also has negative consequences for the environment and biodiversity, including deterioration of coastal ecosystems by aquaculture effluents and impacts on wild species used as feed (*15*). The continuity of present rates of domestication and the capacity of aquaculture to meet the rising demands for seafood of a growing human population require that, by minimizing environmental impact, a sustainable model be achieved. Domestication should aim at closed production cycles, where feed is produced in the farm and the target organisms reproduce and grow from egg to adult in culture, reducing pressures on wild stocks.

The increase in aquaculture has global consequences, both as a food source and in terms of environmental implications. The development of aquaculture is bound to replace fisheries as animal husbandry replaced hunting on land. This should help release pressure on increasingly scarce freshwater resources used to produce food on land, and stimulate technological developments. These changes will modify employment and livelihood patterns of those involved in this industry. The growth in the domestication of marine biodiversity thus represents a fundamental change in the way humans relate to the oceans.

Global pace of species domestication

Species group	Number of species domesticated	Time since domestication (years before present)		Specific growth in the number of domesticated species (% year^{-1})
		50% species domesticated	90% species domesticated	
Land plants	250	4000	2000	0.026 (76)
Land animals	44	5000	146	0.014 (30)
Freshwater animals	180	22	4	3.4 (180)
Marine animals	250	19	4	3.3 (250)
Marine plants	19	32	<10	2.5 (19)

Rates of change. The numbers of presently domesticated species, the times by which 50% or 90% were domesticated, and the rates of domestication differ widely between land and aquatic species. In the last column, the specific growth in the number of domesticated species is defined as the percent increase in the number of species domesticated per year over the period of fastest domestication rates (*6*); the number of species for which domestication dates were available is given in parentheses.

References and Notes

1. D. Normile, *Science* **275**, 309 (1997).
2. A. M. Mannion, *Progr. Phys. Geogr.* **23**, 37 (1999).
3. J. Diamond, *Nature* **418**, 700 (2001).
4. E. B. Hale, in *The Behaviour of Domestic Animals*, E. S. E. Hafez, Ed. (Bailliere, Tindall and Cassell, London,1969), pp. 22–42.
5. FAO, *State of World Aquaculture: 2006. FAO Fisheries Technical Paper. No. 500.* (UN Food and Agriculture Organization, Rome, 2006); see www.fao.org/fidefault.asp.
6. Materials and methods are available as supporting material on *Science* Online.
7. B. Groombridge, M. D. Jenkins, Eds., *Global Biodiversity: Earth's Living Resources in the 21st Century* (World Conservation, Cambridge, UK, 2000).
8. P. Sorgeloos, *World Aquaculture* **30**, 11 (1999).
9. FAO, *Fishstats. FAO Fishery Information, Data and Statistics Unit (FAO-FIDI). 2004—Collation, Analysis and Dissemination of Global and Regional Fishery Statistics. FI Programme Websites* (UN Food and Agriculture Organization, Rome, 2006); see www.fao.org/fi/default.asp.
10. P. J. W. Olive, *Hydrobiologia* **402**, 175 (1999).
11. FAO, *FAOSTAT-Agriculture* (UN Food and Agriculture Organization, Rome, 2006); see www.faostat.fao.org/default. aspx.
12. R. S. V. Pullin, in *Biodiversity, Science and Development: Toward a New Partnership*, F. Di Castri, T. Younes, Eds. (Cambridge Univ. Press, Cambridge, UK, 1996), pp. 409–423.
13. L. Curry Woods III, *Aquaculture* **202**, 343 (2001).
14. A. Neori *et al.*, *Aquaculture* **231**, 361 (2004).
15. R. L. Naylor *et al.*, *Science* **282**, 883 (1998).

16. Supported by the projects SAMI and MarBEF Network of Excellence, funded by the European Commission. We are indebted to Y. Olsen and D. Soto for insights and comments that have greatly improved this work, J. Guieu for help in compiling data, and S. Agustí and S. Zanuy for helpful suggestions.

Supporting Online Material
Materials and Methods
Table S1
References

10.1126/science.1138042

EVOLUTION

Aging and Sexual Conflict

Aging of male organisms and of their sperm reduces fertility and embryo viability, leading to evolutionary conflict between the sexes.

Rebecca Dean, Michael B. Bonsall, Tommaso Pizzari

In many human societies, men are becoming fathers increasingly late in life, and it is estimated that fertility problems experienced by one-third of couples can be attributed to male factors, including aging (*1*). Aging can affect male reproductive success through two processes, each with distinct evolutionary implications: the age of the male and the age of his sperm. Recent empirical studies demonstrate that both male aging and sperm aging may have a dramatic impact on fertility, embryo viability, and ultimately on the evolutionary conflict between sexual partners, known as sexual conflict.

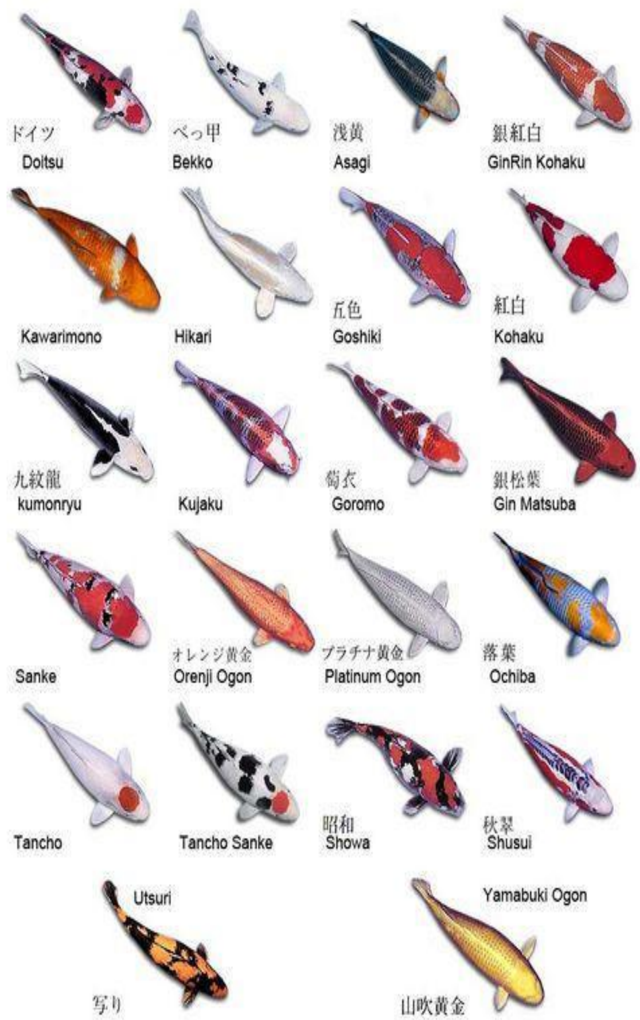
Male fertilizing efficiency is especially important in species where females mate with multiple males and the ejaculates of different males compete for fertilization, a process called sperm competition. One recent study of the hide beetle (*Dermestes maculates*) (*2*) reveals that male aging may be an important determinant of the outcome of sperm competition. The study analyzed fertilization success in two scenarios: when the ejaculates of two males were inseminated into a female (sperm competition), and when the ejaculate of only one male was inseminated (absence of sperm competition). The study demonstrates that the fertilizing ability of an ejaculate peaks at an intermediate male age. Most young males copulated with females but only 36% of them had developed mature sperm, indicating that most young males were not sexually mature. Similarly, although all old males produced mature sperm, some of them failed to transfer sperm during mating (aspermic copulation). Males in their prime (intermediate age), on the other hand, never failed to inseminate a female. Moreover, in sperm competition, their ejaculates outcompeted those of old and young males in fertilizing the eggs of a female. These results confirm earlier work on this species showing that a female incurs

The authors are at the Edward Grey Institute, Department of Zoology, University of Oxford, Oxford OX1 3PS, UK. E-mail: tommaso.pizzari@zoo.ox.ac.uk

Pictures of Domesticated Fish Example
as compared to popcorn

Aqua-Pop-Culture

Teaching about domestication in agriculture and aquaculture.



PowerPoint on Domestication and Aquaculture
(paper copy)

The story of domestication

Elisa Livengood

Definition

Domestication: To train or adapt a plant or animal to live in a human environment making it fit for cultivation. This can be done by having humans intervene in the breeding of plants or animals and selecting traits that are of use to the human.

Map of Domestication

History of Domestication

- Developments accelerated during the Neolithic period (8,000-3,00 B.C.) as environmental conditions become more favorable.
- Animal husbandry evolved from herding and penning wild animals.
- Required keeping animals for many generations until significant changes were made to behavioral, physical, and genetic attributes as selected for by humans.

History of Domestication

- Dog -10,000-8,000 B.C.
- Goat -8,000-7,000
- Sheep- 8,000-7,000
- Pig- 7,000
- Cattle -6,400
- Horse- 4,000
- Camel- 2,600
- Cat 1600-500
- Fish- Many species still not considered fully domesticated

Breeds

Fish can also be domesticated. One of the oldest know domesticated species is Koi or *Cyprinus carpio*.

Like the dog they can have many varieties; it depends on what traits were selected.

Aquaculture

What is aquaculture?

-Aquaculture is agriculture. Farming in water.

- Requires <u>domestication</u> of a plant or animal for <u>production</u>.

History of Aquaculture

- Evidence of Egyptians doing pond culture (2052-1786 B.C.)
- Romans kept eel and cultivated in ponds or cisterns connected to their homes.
- The Hawaiian people practiced aquaculture by constructing fish ponds, an example from ancient Hawaii is a pond at Alekoko dating back at least 1000 years.
- Japanese began farming oysters about 3,000 years ago.

History of Aquaculture

Give a man a fish and he will have food for a day.

Teach a man to fish and he will have food for a lifetime. – Chinese proverb.

NOW we should add

Teach a man how to grow fish and he can feed the world.

Also biblical reference to ponds

And they shall be broken in the purposes thereof, all that make sluices and ponds for fish (Isaiah, Ch. 19 vs. 10).

Aquaculture/Agriculture

- Domestication: where breeding is controlled and animals are selected for particular qualities.
- Aquaculture production is achieved by human intervention involving physical control of the organism at some point in its life cycle other than harvest.

Criteria for Selecting a Species

- Hardiness
- Fecundity (high reproductive success)
- Early Sexual Maturity
- High Meat/Protein Content
- Market Value
- Ease for culture (e.g., life cycle established, larval feeds available, domesticity)