**Seafood Watch**
Seafood Report

MONTEREY BAY AQUARIUM®

# U.S. Farmed Sturgeon

*White sturgeon (Acipenser transmontanus)*
*Siberian sturgeon (Acipenser baerii)*
*Russian sturgeon (Acipenser gueldenstaedti)*
*Sevruga sturgeon (Acipenser stellatus)*
*Beluga sturgeon (Huso huso)*

White sturgeon, Illustration © Monterey Bay Aquarium

January 27, 2007

Zdravka Tzankova
Independent Consultant

## About Seafood Watch® and the Seafood Reports

Monterey Bay Aquarium's Seafood Watch® program evaluates the ecological sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch® defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. Seafood Watch® makes its science-based recommendations available to the public in the form of regional pocket guides that can be downloaded from the Internet (seafoodwatch.org) or obtained from the Seafood Watch® program by emailing seafoodwatch@mbayaq.org. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Each sustainability recommendation on the regional pocket guides is supported by a Seafood Report. Each report synthesizes and analyzes the most current ecological, fisheries and ecosystem science on a species, then evaluates this information against the program's conservation ethic to arrive at a recommendation of "Best Choices", "Good Alternatives" or "Avoid". The detailed evaluation methodology is available upon request. In producing the Seafood Reports, Seafood Watch® seeks out research published in academic, peer-reviewed journals whenever possible. Other sources of information include government technical publications, fishery management plans and supporting documents, and other scientific reviews of ecological sustainability. Seafood Watch® Research Analysts also communicate regularly with ecologists, fisheries and aquaculture scientists, and members of industry and conservation organizations when evaluating fisheries and aquaculture practices. Capture fisheries and aquaculture practices are highly dynamic; as the scientific information on each species changes, Seafood Watch's sustainability recommendations and the underlying Seafood Reports will be updated to reflect these changes.

Parties interested in capture fisheries, aquaculture practices and the sustainability of ocean ecosystems are welcome to use Seafood Reports in any way they find useful. For more information about Seafood Watch® and Seafood Reports, please contact the Seafood Watch® program at Monterey Bay Aquarium by calling (831) 647-6873 or emailing seafoodwatch@mbayaq.org.

### Disclaimer

Seafood Watch® strives to have all Seafood Reports reviewed for accuracy and completeness by external scientists with expertise in ecology, fisheries science and aquaculture. Scientific review, however, does not constitute an endorsement of the Seafood Watch® program or its recommendations on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

Seafood Watch® and Seafood Reports are made possible through a grant from the David and Lucile Packard Foundation.

# Table of Contents

## Executive Summary

Sturgeons (order *Acipenseriformes*, family *Acipenseridae*) are among the oldest living vertebrates, with fossil records dating back more than 150 million years. All 26 species of sturgeon are found exclusively in the Northern hemisphere. All sturgeons are depleted worldwide, with several sturgeon species currently threatened with extinction. This is the result of over a century of exposure to the combined pressures of overfishing and environmental degradation. Much of the former has been driven by the consistently high value of caviar, which remains among the most expensive of fishery products. The latter has included the accumulation of pollutants in sediments, as well as the damming of rivers and restriction of water flows, both of which have worked to impede reproduction and migration.

Generally, it is the depletion of wild sturgeon stocks that created the motivation for artificial propagation and rearing of sturgeon. Artificial reproduction was initially pursued with the goal of supplementing wild stocks and augmenting sturgeon fisheries. Increasingly, commercial sturgeon culture is pursued as a method of direct caviar production, with farmed caviar emerging as an increasingly valued supplement and substitute for wild caviar, whose production and supply are declining with the continuing decline of wild sturgeon populations and in spite of the fact that many such populations, including those in the Caspian, are maintained through hatchery programs.

In spite of the advances in knowledge of sturgeon embryology, reproductive biology, and hatchery techniques that occurred in the process of developing and applying re-stocking and augmentation programs, as late as the early 1980s it was still unclear whether sturgeon can be successfully adapted to commercial grow-out systems (Doroshov, 1985).

This all changed with the successful closing of the life cycle for white sturgeon in captivity, attained in California in the early 1980s as a result of the research and experimental work of several UC Davis scientists working under the research leadership of Dr. Serge Doroshov and in collaboration with interested aquaculturists. Later followed by closing the life cycles in captivity for several other sturgeon species, this development effectively enabled the expansion of sturgeon farming for meat and caviar beyond the small, experimental scale on which it was taking place and into the types of commercial production that are described and evaluated in this report.

In the U.S., five species of sturgeon – white, Siberian, Russian, beluga, and stellate - are currently farmed in two types of culture systems – tanks and raceways, with most tank systems relying on ground water, while raceways rely primarily on spring water and to a limited extent on stream water. Many tank-based facilities apply various degrees of recirculation before discharging their water, and some farms practice almost complete recirculation with minimal effluent. In the case of California operations, much of the effluent discharged by some of the larger facilities goes to wetlands and agricultural irrigation. The size of farming operations as well as the production volumes of various sturgeon culture companies vary considerably, with two of California's three sturgeon culture operations currently considered the largest in the U.S. It is, however, important to note that sturgeon culture operations, even the largest of which currently produce no more than several tons of caviar and several hundred tons of sturgeon meat annually, remain small in comparison to most other types of aquaculture operations, for example those focusing on the production of trout, tilapia, or catfish.

Commercial U.S. culture of sturgeon for meat and caviar is currently taking place in three states – California, Idaho, and Florida, with others, such as Hawaii and Georgia, also poised for the development of sturgeon aquaculture. U.S sturgeon culture is currently dominated by the production of white sturgeon. Most of this is accounted for by three tank-based California operations. Raceway-based Idaho sturgeon culture operations are also exclusively focused on the production of native strains of white sturgeon, although their current scale and production capacity is nowhere near those of California operations, which, albeit having changed ownership several times over the past few decades, are the oldest sturgeon aquaculture facilities in the U.S. Although white sturgeon currently dominates U.S. meat and caviar production, the Florida operations, which culture four European species and which have just begun their caviar harvest, are reportedly expected to quickly catch up to the combined production volumes of California and Idaho operations.

It is reported that many aquaculturists and entrepreneurs are currently looking to enter sturgeon culture in order to take advantage of the growing interest in, and market for farmed sturgeon caviar. With farmed caviar having considerable potential to alleviate the pressures on wild sturgeon, this situation calls for ongoing scrutiny of the nature of sturgeon aquaculture practices and their environmental impacts to make sure that the promising conservation potential of sturgeon aquaculture is indeed being realized.

Over-all, U.S. farmed sturgeon and caviar rank as a “Good Alternative” according to Seafood Watch® criteria. Given current production methods, effluents pose no environmental or ecological concern. There are ecological risks associated with farmed fish escapes where non-native sturgeon species are the focus of commercial production. However, the nature of current containment practices and the reported record of total escape prevention for the Florida facilities that presently culture non-native sturgeons suggest currently low exposure for wild sturgeon stocks to the ecological risks of farmed fish escapes. There is some concern that disease outbreaks in farmed populations may affect wild fish populations, although there is presently no evidence that such effects have actually occurred. The disease transmission concern is essentially due to sturgeon farm releases of wastewater which may contain disease-causing organisms. The risks of disease transfer from farmed to wild sturgeon have consequently been ranked as “Moderate.” Current evidence also suggests that U.S. sturgeon culture operations, across the three states where they are located, are managed effectively in regulatory terms. The biggest ecological concern associated with sturgeon aquaculture as currently practiced remains its fairly high use of marine resources in the form of feed. Although the amount of fishmeal and fish oil used in sturgeon feed, as well as the feed conversion ratios of cultured sturgeon may decrease in the future, their current levels warranted a red, or “Extensive use of marine resources” ranking at the present time.

## Table of Sustainability Ranks

| **Sustainability criteria** | **Conservation Concern** | | | |
|---|---|---|---|---|
| | **Low** | **Moderate** | **High** | **Critical** |
| Use of marine resources | | | √ | |
| Risk of escapes to wild stocks | √ | | | |
| Risk of disease and parasite transfer to wild stocks | | √ | | |
| Risk of pollution and habitat effects | √ | | | |
| Effectiveness of management | √ | | | |

## Overall Seafood Recommendation for U.S. Farmed Sturgeon and Caviar

Best Choices 🟩 [✓ Good Alternative 🟨] Avoid 🟥

# Introduction

First initiated in California in the mid-1980s, the intensive commercial farming of sturgeon for caviar and meat still represents a small segment of U.S aquaculture when it comes to net production volumes or the number and size of production facilities. Sturgeon culture, however, is distinct with the high value of its products. Indeed, it is unique when it comes to the nature and price of its key target – caviar.

Farmed-origin caviar, which now generally retails between $ 104 and $ 237 per 50 grams (depending on quality) is still somewhat cheaper than the most prestigious varieties of wild caviar (sterlingcaviar.com; tsarnicoulai.com; markyscaviar.com; petrossian.com; caviar.com), but it is among the highest value aquaculture products on the market today.[1] Furthermore, the highest quality farmed caviar – such as some Siberian sturgeon caviar from Europe and some white sturgeon caviar produced in California - is increasingly approximating the prices – as well as status - of the most highly valued wild varieties, and even surpassing the prices for some wild sevruga and osetra.

The intensive commercial culture of sturgeon - to be distinguished from activities such as captive reproduction and stocking of fingerlings to augment sturgeon fisheries, is also distinct in terms of the length of the production process and the complexity of some of its individual stages.

The latter notwithstanding, the significance of sturgeon aquaculture as a source of caviar for the world market has been growing in the past decade – a trend that is the combined result of several developments: ecological and policy developments reducing the world supply of wild caviar, advances in intensive sturgeon culture both in the U.S. and in a number of European countries, and gradual shifts in the preferences of high-end consumers and purveyors from an exclusive focus on wild caviar varieties to gradual and currently even enthusiastic acceptance of farmed-origin caviars.

The key ecological dynamic responsible for the growing market status of farmed-origin caviar as well as for the increasing interest in intensive sturgeon culture is the ongoing and recently accelerating decline of most wild sturgeon populations, especially Caspian populations of beluga, stellate (sevruga), and Russian (osetra) sturgeons, which have long supplied the majority of caviar for the world market (Raymakers, 2002; Williamson, 2003). These declines are reflected in unprecedented new lows in world sturgeon catches, which reached 5, 723 tons in 1995 and 3, 715 tons in 1998 (Raymakers, 2002) after averaging around 17, 500 tons during the late 1940s and fluctuating between 13, 500 and 31, 400 tons in the 1960s and 1970s (Raymakers and Hoover, 2002).

The decline of wild sturgeon populations has also affected the market availability for wild varieties of caviar by prompting several national and international bans on caviar trade. The bans

---

[1] High quality bluefin tunas produced in Australian, Mexican, or European tuna ranching facilities and sold as sushi-grade fish, and in particular the choice cuts of such tunas, are probably among the few aquaculture products that can begin to compare to caviar in terms of high market price.

have been instituted to aid the recovery of certain sturgeon stocks by greatly restricting the legal market for caviar from these stocks and thereby reducing fishing pressure through eliminating much of the incentive for sturgeon fishing.[2]

Intensive commercial culture of sturgeon for meat and caviar is currently taking place in several countries, including the U.S., France, Italy, Spain, Germany, Austria, Hungary, Belgium, the Russian Federation, China, and Uruguay (Williot et al., 2005; Wei et al., 2004; Arndt et al., 2002; Raymakers, 2002; Ivakhnenko, 2001; Williot et al., 2001). From the 25 species of sturgeon (family Acipenseridae) and two species of paddlefish (family Polyodontidae) that constitute the order Acipenseriformes, several are the primary focus of intensive commercial culture. These include the North American white sturgeon (*Acipenser transmontanus*), Siberian sturgeon (*Acipenser baeri*), and Adriatic sturgeon (*Acipenser naccarii*). Several other species, including sevruga (or stellate) sturgeon (*Acipenser stellatus*), Russian sturgeon (*Acipenser gueldenstaedti*), beluga sturgeon (*Huso huso*), and American paddlefish (*Polyodon spathula*) are also used.

Some of the existing farming operations focus on the culture of native species and strains of sturgeon, while others rely on the culture of sturgeon species exotic to the region where production takes place. The choice often depends on a combination between the economic and technical aspects of production on the one hand and the regulatory setting on the other. For example, technical and research support in the form of university or extension programs and/or hatchery facilities is often available for certain species in certain locations; some sturgeon species, such as white sturgeon, are better suited to commercial culture (Van Eenennaam et al., 2004), yet others, such as beluga, hold a potentially higher promise in terms of the market price and potential for their caviar. Since introduction into the wild of non-native species of sturgeon poses a major concern, especially in aquatic systems where native sturgeon species are present, many jurisdictions restrict or prohibit the import and/or rearing of non-native sturgeons, thereby influencing the selection of species for culture. In other cases, however, it is the culture of native species, where the native species are listed or about to be listed as threatened or endangered that is restricted or prohibited for commercial purposes. This is currently the case in the state of Florida, where ESA-based restrictions from the US Fish and Wildlife Service have ruled out the commercial aquaculture of native Florida species, all of which are either listed or about to be listed under the Endangered Species Act. As a result, after an initial interest in the commercial culture of native species, Florida aquaculturists have focused on several popular European species whose decreasing availability in the wild is contributing to the market for cultured caviar.

In Western Europe, production is dominated by three species – North American white sturgeon (*Acipenser transmontanus*), Siberian sturgeon (*Acipenser baeri*), and Adriatic sturgeon (*Acipenser naccarii*) (Williot et al., 2001).

---

[2] The most important recent restrictions on caviar trade include an October 2005 U.S. ban on the imports of beluga sturgeon products from the Caspian and Black Sea regions instituted under the U.S. Endangered Species Act, and a broader ban on international trade in caviar from the world's three top-producing river basins – the Caspian Sea basin, the Black Sea - lower Danube River basin, and the Amur River basin, instituted on January 3, 2006 under the authority of the Convention on Trade in Endangered Species of Wild Flora and Fauna (CITES) (Raloff, 2006; Caviar Emptor Press Room, http://www.caviaremptor.org/releases.html ).

U.S. intensive sturgeon culture is currently dominated by the production of native white sturgeon (*Acipenser transmontanus*), which takes place in California and Idaho, with native Sacramento-San Joaquin and Snake River strains, respectively, cultured in each state's facilities. The culture of several European species, however, including Siberian sturgeon (*Acipenser baeri*), Russian sturgeon (*Acipenser gueldenstaedti*), Stellate sturgeon (*Acipenser stellatus*) and beluga sturgeon (*Huso huso*) is coming of age in Florida, where three commercial farms are about to do their first caviar harvest this year (2006) (Frank Chapman, Personal communication; Salisbury, 2006).

## Scope of the analysis and the ensuing recommendation

This report focuses on characterizing and evaluating sturgeon culture in the United States, and makes recommendations about the sturgeon meat and caviar produced by U.S. aquaculture operations and available to U.S. consumers. The report covers five sturgeon species reared in three states and evaluates the meat and caviar products that currently come from these operations.[3]

The American paddlefish, *Polyodon spathula*, which is currently cultured on several U.S. aquatic farms (Mims, 2001; Williamson, 2003; Van Eenennaam et al., 2004; Chapin, 2006) is intentionally excluded from this report for several reasons. Most important among them are the specifics of the of the paddlefish diet: paddlefish is quite different from other sturgeon species in that it is a filter feeder that depends on plankton, while all other sturgeon are carnivores. Consequently, more extensive culture techniques that do not necessarily depend on external feed inputs, such as reservoir ranching, are used in current and considered for future paddlefish farming operations in the U.S. (Mims, 2001; Williamson, 2003; Van Eenennaam et al., 2004), while sturgeon culture, as will be discussed in the following sections, is intensive and highly dependent on external feed inputs that contain considerable amounts of fish protein in the form of fishmeal and fish oil. Such differences between the farming practices suitable for paddlefish and those used for other sturgeon species strongly suggest the need for separate assessments of sturgeon and paddlefish culture. Additionally, in spite of some recent developments, including the beginning of some caviar production on at least one of the facilities that are currently holding paddlefish, the U.S. culture of paddlefish is still largely in a research and development phase (Mims, 2001; Van Eenennaam et al., 2004).

In a context where the U.S. is, alongside Japan and EU, one of the major importers and consumers of caviar – both farmed and wild – some of the farmed caviar available on the U.S. market is of foreign origin. However, the relative novelty of commercial sturgeon culture for meat and caviar, the small scale of such culture, and its very small share in total aquaculture production – across national context and internationally, make it difficult at the present time to

---

[3] A lot of the analysis and evaluation is effectively based on the culture of white sturgeon in California and Idaho, where the six oldest and most established in terms of their practices facilities, as well as the only facilities with current caviar production, are located. Emerging sturgeon culture operations, such as the three Florida farms that are currently developing the culture of European species for caviar production are covered to the greatest extent permitted by the available data, given a context of ongoing adjustments in production processes and practices in those more recently established facilities.

obtain data of the detail and reliability needed for a rigorous sustainability assessment of foreign sturgeon culture operations.

At least one group, however, is currently working on evaluating the sustainability of several major European producers (Julia Roberson, Personal Communication). The results of their research, expected in early 2007, should provide a valuable complement to this report and so far suggest that the sustainability ranking for much of European farmed sturgeon and caviar should be comparable to the rankings given U.S. facilities and products on the basis of this research. Further, several Chinese scholars have begun surveying and documenting the extent and nature of an apparently growing though so far not officially studied or documented sturgeon culture sector in China (Wei et al., 2004). Their work should provide especially valuable and otherwise difficult to obtain data and insight for a future sustainability assessment of sturgeon culture outside of the U.S.

## Sturgeon aquaculture in the U.S.

### ***A brief sector profile***

Communications with university researchers, extension specialists, and sturgeon farm personnel, internet research, and a review of the available peer-reviewed and gray literature suggested that nine intensive commercial aquaculture operations are currently responsible for the overwhelming majority of sturgeon meat and caviar produced in the U.S. Three of these operations are located in California, three in Idaho, and three in Florida.[4] Some of these nine operations have culture facilities in several adjacent locations. One of the Florida operations – at the Mote Marine Labs - combines sturgeon culture research with the commercial production of sturgeon for meat and caviar. Several of the farms, such as Stolt Sea Farms in California, are exclusively dedicated to sturgeon culture. Others, such as the three Idaho farms, culture sturgeon in addition to other species, most importantly trout. The Tsar Nicoulai company in California is currently considering the incorporation of a polyculture element with hydroponic cultivation of vegetables, herbs and spices that utilize nutrient-rich water recirculated on the farm (Tsar Nicoulai Website, October 13, 2006; Cliff, 2005; Dr. David Stephen, Personal Communication). Currently, the farm is using water hyacinth as a nutrient absorber, because although the plant lacks commercial value, it is efficient at nutrient absorption, and unlike most herb and vegetable crops is not labor-intensive to tend to.[5]

In addition to the nine established sturgeon culture operations, a small number of sturgeon are apparently kept, on a mostly experimental basis, on farms whose primary focus is the culture of other species. Several such farms are reported to exist in Idaho (Dr. Terry Patterson, Personal

---

[4] There is an indication that one of the Idaho farmers may be retiring and selling his stock to a California operation (Gary Fornshell, Personal communication).

[5] It is important to note that although water hyacinth is an invasive aquatic species in the U.S., the Tsar Nicoulai sturgeon culture facility did not introduce it for the purposes of their farming operations, but rather used water hyacinth already present in its region's water bodies. Further, and most importantly, when the farm "harvests' water hyacinth that is redundant in its recirculation ponds, it disposes of it on a land site where it is kept until completely dried out (Dr. David Stephen, Tsar Nicoulai Farm Scientist, Personal Communication; The researcher also visited the Tsar Nicoulai facility and witnessed the nature of its recirculation pond and land disposal facilities).

communication; Gary Fornshell, Personal Communication), and it is possible that some of them sell some sturgeon, most likely juvenile sturgeon for meat and/or the live seafood market. Hawaiian aquaculturists have also expressed interest in adding sturgeon to their current range of cultured species, although there are no commercial scale activities taking place in Hawaii as of the present time (Dr. Frank Chapman, Personal Communication[6]). No more precise information is available on any of these smaller and/or experimental operations.

Finally, research is being conducted in the University of Georgia Cohutta Fisheries Research Center to evaluate the feasibility of commercial sturgeon farming in Georgia and the Southeast. The Center currently has four cohorts of Siberian sturgeon (*Acipenser baeri*), and is about to conduct the first caviar harvest and a market testing of the caviar produced in several years. If the results of this research and of the upcoming caviar harvest are promising, intensive commercial culture operations in Georgia and other Southestern states are the likely result.[7]

Tank systems – primarily circular tanks made of corrugated iron or fiberglass, and concrete raceways are the two types of systems currently used by U.S. sturgeon farms, in addition to some specialized hatchery facilities for those farms that produce their own fry. All six California and Florida facilities rely on tank culture, while the three Idaho farms are using the raceways that were already available from pre-existing trout farming operations (Van Eenennaam et al., 2004; Gary Fornshell, Personal Communication; Dr. Frank Chapman, Personal Communication).

The tank systems are generally supplied by ground water. Individual tanks usually range from 7 to 15 meters in diameter, and most of the tank culture facilities use various degrees of water recirculation (Peter Struffenegger, Personal Communication; Frank Chapman, Personal Communication; Cliff, 2005).

Idaho raceways rely primarily on spring water and to a limited extent on stream water and operate as flow-through systems, discharging into receiving streams (Gary Fornshell, Personal Communication).

All U.S. sturgeon culture can be clearly classified as intensive. All U.S. operations rely exclusively on formulated feeds, and although some sturgeon farming facilities, such as Tsar Nicoulai's California farm, work to incorporate natural ecological processes into their system of production – such as water recirculation and the use of aquatic plants for nutrient uptake, the production cycle is closely controlled and ultimately dependent on the strictly calculated input of resources, including oxygen.

White sturgeon (*Acipenser transmontanus*), the species cultured by all the California and Idaho farms, clearly dominates current U.S. production of both caviar and sturgeon meat (Mims, 2002;

---

[6] Also see the following reporting document on research for improving sturgeon farming in Hawaii for some further detail:
http://www.ctsa.org/upload/project/2004_Final_Report_Sturgeon_Yr_16324460732444668180.pdf

[7] See University of Georgia's summary of the relevant research at
http://www.forestry.uga.edu/h/research/fishandaqua/fishandaqua/siberian/
Also note that the University of Georgia facilities involved with sturgeon culture research were listed as a sturgeon aquaculture operation in USDA's Census of Aquaculture for 2005.

Van Eenennaam et al., 2004; Dr. Van Eenennaam, Personal Communication; Dr. Frank Chapman, Personal Communication). In addition, although exact production numbers are still very difficult to obtain, it is clear that California currently dominates the U.S. production for both caviar and meat (Dr. Van Eenennaam, Personal communication; Dr. Terry Patterson, Personal communication; Peter Struffenegger, Personal Communication).

In terms of production statistics – a single, uniform and reliable source of figures on the volumes and/or values of U.S. farmed caviar production is not available. Different publications usually provide production statistics for a particular year and/or a particular company. Some potential contradictions also exist in the production data currently available. For example, Mims et al. (2002) approximate the 2000 U.S. production of farmed white sturgeon caviar at 4 tons. Williamson (2003, p. 206) on the other hand puts the estimated 2002 caviar production by California's Stolt Sea Farm alone at 4545 kg (4.5 tons). More recently, Van Eeneennaam et al. (2004, p. 294) put the 2003 total California production of white sturgeon caviar at 7 tons. One individual operation indicated that it is likely to reach a 10 ton caviar harvest this year (2006). Estimates and/or actual numbers for Florida operations, who have their first harvests taking place at the end of 2006 – early 2007 are not available, but with those operations maturing to the caviar production stage, over-all production should continue to increase.

Data on the production of sturgeon meat from the same U.S. operations put meat volumes at 600 tons in 2000 (Mims et al., 2002) and estimate volumes to have fluctuated between 700 and 900 tons a year over the past few years (Van Eenennaam et al., 2004).

Although the exact annual levels of U.S. farmed caviar and meat production remain difficult to pin down, a clear trend of considerable growth in intensive sturgeon culture is evident from the available data, in spite of its fragmented quality.

### ***Intensive sturgeon culture: the production process***

As a taxonomic group, sturgeon have many unique biological, morphological, and life history characteristics that distinguish them from most modern teleost fishes, for example the longevity of many sturgeon species, their large body size, cartilaginous skeleton, and external bony plates, their late sexual maturation and long gametogenetic cycles.[8]

Consequently, while the culture of sturgeon as currently practiced resembles the culture of other aquatic species when it comes to the types of production systems and feeds used or the types of regulatory requirements applicable to aquaculture operations, sturgeon's unique biology and life history, and the distinct culture challenges these entail, including a long caviar production cycle, make sturgeon farming a rather singular aquaculture activity.

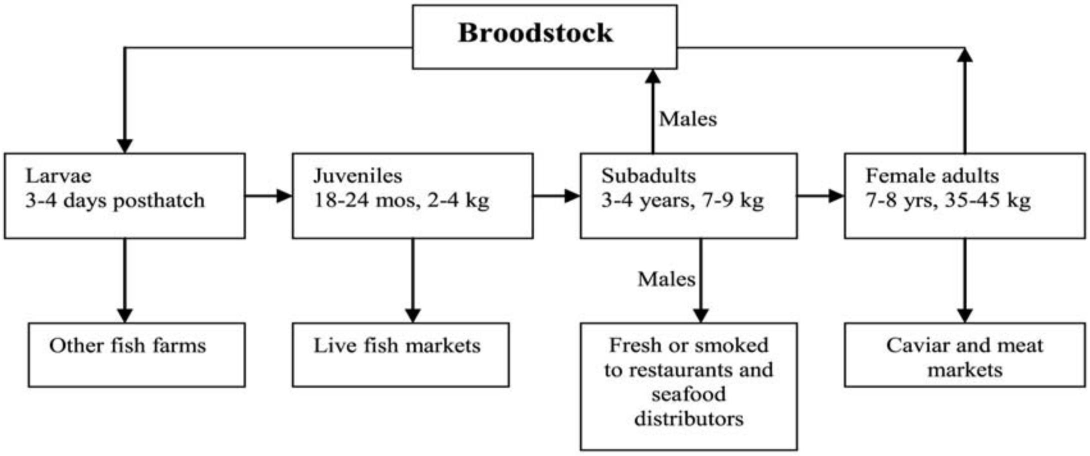
The most important stages of the commercial rearing of sturgeon for meat and caviar are illustrated in Figure 1 below. The ages and weights of fish at different stages of production, as

---

[8] For a detailed treatment of the biology and life history of Acipenseriformes, as well as for a discussion of the major conservation challenges facing the world's sturgeon and paddlefish, see Binkowski and Doroshov, 1985; Dettlaff, Ginsburg, and Schmalhausen, 1993; Birstein, Waldman, and Bemis, 1997; Van Winkle et al., 2002; Williamson, 2003; LeBreton, Beamish, and McKinley, 2004; and McDougall, 2005.

listed in the figure, reflect the commercial production of white sturgeon in California, but the over-all process captured in the figure is a good summary for the range of U.S. sturgeon culture operations.

**Figure 1: The general production scheme of a U.S. commercial sturgeon operation (white sturgeon)**



(From Van Eenennaam et al., 2004, p. 292)

The hatchery phase in sturgeon production involves several stages and was, until relatively recently, attended by a number of unique challenges, such as the difficulty of obtaining sexually mature, spawning-ready adults from the wild; the relative difficulty of and special procedures required for determining spawning readiness, especially for female sturgeon; the inability of sturgeon to spawn naturally under hatchery conditions due to the absence of environmental cues; the need for a surgical egg collection if the female is not to be sacrificed during spawning; and the extreme stickiness of newly fertilized sturgeon eggs, which cluster together and can be thereby difficult to handle without damage (Doroshov, 1985; Binkowski and Doroshov, 1985; Mims, 2002; Van Eenennaam et al., 2004).

All of these difficulties in artificial propagation have been largely overcome as a result of research-driven developments in sturgeon spawning, fertilization, and incubation techniques over the past few decades (Doroshov, 1985; Conte et al., 1988; Mims, 2002; Van Eenennaam et al., 2004). Most importantly, the closing of the reproductive cycle in captivity for all sturgeon species currently cultured in the U.S. (Mims et al., 2002; Van Eenennaam et al., 2004; Dr. Frank Chapman, Personal Communication) means that commercial farming no longer depends on the capture, transport, and spawning of mature wild fish.

The sturgeon culture cycle now starts with the spawning induction of domesticated broodstock. Milt and eggs are collected without sacrificing the broodfish, with egg collection generally requiring one of two types of surgical procedures: Caesarian section, or a surgical technique known as MIST (minimally invasive surgical technique). Since the gonadal cycles for most sturgeon species are not annual, the broodstock are carefully monitored for gonadal maturity. In captive reared white sturgeon, which accounts for the majority of current U.S. meat and caviar production, gonadal cycles are annual for males and biennial for females (Doroshov et al., 1997). Similar patterns have so far been observed for most of the European species reared in Florida, although further research is needed to conclusively characterize the nature of reproductive cycles for the captive populations of these species (Dr. Frank Chapman, Personal Communication). Given the high fecundity of sturgeon, only several males and females are usually spawned for the production of each new year-class.

Following incubation, larval fish are transferred to cultivation tanks, where stocking densities are usually based on the surface area of the tank bottom so as to create optimal feeding conditions for the typically benthic-oriented young sturgeon (Van Eenennaam et al., 2004). While some sturgeon species require live feeds during their larval stage, larval white sturgeon has shown to be particularly adaptable to prepared feeds from the very beginning of external feeding, which generally starts 3-5 days after hatching, when the fry has nearly used up its yolk sac and right before the excretion of the yolk plug (Mims et al., 2002; Van Eenennaam et al., 2004).

During the growout phase, a few of the current sturgeon culture operations use feeds that have been formulated with some attention to known nutritional specifics for sturgeon, though a totally specialized sturgeon feed is not yet available, and many U.S. facilities still rely on commercial trout feeds (Peter Struffenegger, Personal Communication; Dr. Frank Chapman, Personal communication; Gary Fornshell, Personal Communication; Dr. Terry Patterson, Personal Communication).

Different types of technologies, including flow-through for raceways, and recirculation and the use of plants as biofilters for tank systems are currently used on U.S. farms to maintain high water quality and oxygen levels in the culture systems. (Peter Struffenegger, Personal Communication; Dr. Frank Chapman, Personal Communication; Cliff, 2005). Oxygen is also commonly added to the culture environment.

The water temperatures required by sturgeon for optimal growth and performance are an important distinction of the sturgeon culture process. Many sturgeon species require warm temperatures – e.g. 18 to $26^0$ C - for optimal growth and performance, but need colder water, in the 10 to $15^0$ C range, for spawning and reproduction (Doroshov et al., 1997; Mims et al., 2002; Van Eenennaam et al., 2004). White sturgeon, for example, has been found to grow and perform best when reared at temperatures in the 18 and $23^0$C range (Moberg and Doroshov, cited in Van Eenennaam et al., 2004), while temperatures between 9 and $12^0$ C have been found optimal for the spawning of domesticated broodstock (Van Eenennaam et al., 2004). As a result of these specific rearing requirements, most sturgeon facilities need to be either situated in locations where natural sources of both warmer and colder water are available – for example, geothermal sources or deep aquifers for the warmer water, and cool streams or surface waters for the colder water; or they have to heat or cool the water, which can add substantially to the over-all cost of operations. Alternatively, sturgeon can be cultured in water somewhat colder than the optimal water temperatures, as is the case with culture of white sturgeon in Idaho, which grow their sturgeon at temperatures in the 13 to $17^0$ C range, but farms which rear their fish in colder waters experience slower growth rates. In turn, since the time of sexual maturation for cultured sturgeon has been conclusively linked to growth performance and body weight (Van Eenennaam et al., 2004; Dr. Serge Doroshov, Personal Communication), maturation of caviar-producing females reared in colder water occurs later than that of females reared in warmer water: at an average age of 10 to 12 years versus 7 to 9 years, respectively, for white sturgeon (Van Eenennaam et al., 2004; Gary Fornshell, Personal Communication).

Compared to most other aquatic species farming, sturgeon culture is distinctive with the need to determine the fish's gender, and with the differences in production cycles based on this gender. Namely, females are kept until they reach full sexual maturity and harvested for their caviar, while males are slaughtered for their meat at or before 4 years of age and several kilograms in weight (an average of 7 to 9 kg for white sturgeon).

Because sturgeon have no external sex characteristics, however, the fish's gender is determined through a surgical procedure that takes a sample of the gonadal tissue once the fish have passed the age of sexual differentiation, which is between 2 and 4 years of age for the species currently cultured. The surgical sexing of sturgeon generally takes place at 3 to 4 years of age for white sturgeon cultured in California, 4 to 5 years for white sturgeon in Idaho, and 2 to 3 years of age for the European species currently reared in Florida farms (Dr. Frank Chapman, Personal Communication).

After the sexing of fish, and the harvesting of most males (except those kept as broodstock) for the sturgeon meat market, the final step in the sturgeon culture process is the ongrowing of females until they reach sexual maturity and are ready for the harvesting of caviar. Females are slaughtered in the process of caviar harvest, and their meat is also utilized for human consumption. Mature white sturgeon females currently cultured in U.S. facilities usually weigh between 35 and 45 kg and yield between 9 and 12% of their body weight as caviar eggs, although some (usually small) percentage of the eggs harvested does not make the caviar grade. Average numbers for caviar yield have not yet been established for the other species of European sturgeon currently cultured in Florida, as those operations are still developing and standardizing their process, and have yet to complete their first caviar harvest, planned for this year (2006).

The caviar from each fish is processed separately, because of differences in the egg size and quality, which lead to different grading, and ultimately – different pricing. Such differences generally make it unsuitable to package caviar from different females into the same tin.

## Availability of science

Research relevant to sturgeon culture remained, until recently, primarily focused on embryology, reproductive biology, and the development and application of various techniques involved in artificial reproduction. Work on questions of sturgeon diseases and health management, as well as research on nutrition requirements in captivity is currently gaining momentum, although a lot of questions in key areas such as sturgeon genetics and nutrition are yet to be conclusively answered even for the most established aquaculture species such as white sturgeon.

Understanding of the exact nutrition requirements for most sturgeon species under culture is still in the process of being perfected, and different farmers as well as different research facilities are experimenting with different diet formulations.

Knowledge and literature are considerably scarcer with respect to the environmental impacts of sturgeon culture. Several scientific publications mentioned the risks posed by escapes of farmed sturgeon, including hybridization and possible loss of genetic diversity for native populations, several of them noting the general lack of research attention to the subject (Metcalf and Zajicek, 2001; Raymakers, 2002; Arndt, Gessner, and Raymakers, 2002; Williamson, 2003; Wei et al., 2004).

In this context of relative data scarcity and ongoing scientific inquiry on many key aspects of commercial sturgeon culture, this research has drawn on a combination of peer-reviewed scientific literature, gray literature, and a range of extensive personal communications with with university scientists and extension specialists, as well as with industry scientists and managers. Personal communications and published sources used as the basis for this evaluation are detailed in the *References* section of this report.

## Market Availability

**Common and market names:**

***Scientific names of U.S. farmed species***: *Acipenser transmontanus*, *Acipenser baeri*, *Acipenser gueldenstaedti*, *Acipenser stellatus*, *Huso huso*

***Common names of U.S. farmed species***: White sturgeon, Siberian sturgeon, Russian or osetra sturgeon, Stellate or sevruga sturgeon, beluga sturgeon

***Market names for U.S. farmed caviar***: caviar, white sturgeon caviar, California estate osetra (Tsar Nicoulai), Sterling Caviar, Royal Transmontanus caviar, Tsar Imperial Transmontanus caviar, Alverta caviar

**Product forms:**

Farmed sturgeon caviar is sold both wholesale and retail, with retail sales appearing on the U.S. market under the names and brands listed above, in container sizes generally ranging from 28 grams (1 ounce) to 1000 grams (35 ¼ ounces).

Sturgeon meat is available as live smaller fish (2-4 kg), fresh whole fish, skinless fillets, and various smoked products.

**Market specifics**

To understand the market availability and dynamics for U.S.-farmed caviar, it is important to note several caviar-specific product and marketing dynamics.

First, while several U.S. sturgeon farming companies sell caviar directly through company websites or through retailers under their own brands, most companies, even the largest ones that have their own farmed caviar brands, distribute significant portions of their product through specialty purveyors, such as Petrossian, The Seattle Caviar Company, and Marky's Caviar. The purveyors do not specify the producer or use the producer's own brand, although they do indicate the farmed origin and, often, the general region of provenance for U.S. farmed caviar.

California's Stolt Sea Farm, for example, one of the oldest, largest, and most significant producers, distributes most of its caviar through Petrossian, although it also sells some directly through its website under the Sterling brand (sterlingcaviar.com; Peter Struffenegger, Personal Communication). Florida producers who are about to have their first caviar harvest are also looking into distribution arrangements with Petrossian and other specialty purveyors.

Caviar is marketed based on the species and on quality. Even caviar that comes from the same species and the same company is usually available in several grades (and price ranges) based on the quality, which is defined by taste, as well as size and color of the eggs. Stolt's Sterling Caviar, for example, comes in several grades based on its specific characteristics. These currently include Sterling Classic Caviar, Sterling Royal Caviar, and Sterling Imperial Caviar, priced at $ 63, $ 74 and $ 80 per 30 grams, respectively) (http://www.sterlingcaviar.com). California-produced white sturgeon caviar is also sold by Petrossian in several grades, currently including the Royal Transmontanus Caviar, retailing at $121 for 50 grams, Tsar Imperial Transmontanus at $144 per 50 grams, Alverta Caviar at $163 per 50 grams, and Alverta President Caviar at $195 for 50 grams (http://www.petrossian.com). In comparison, Petrossian sells wild sturgeon caviars such as Tsar Imperial Sevruga Caviar for $ 278 for 50 grams, Imperial Special Researve Stellatus Caviar for $ 305 for 50 grams, and Royal Ossetra for $ 350 for 50 grams (http://www.petrossian.com).

Farmed caviar is usually distinguishable among the numerous caviar products offered by specialty caviar purveyors. Whereas caviar catalogues do not usually specify the exact producer, California farmed caviar is often clearly labeled as such by purveyors such as Marky's, the Seattle Caviar Company, and Petrossian.

Given current U.S. and CITES restrictions on the trade in all sturgeon products (including many farmed products) from several of the world's major caviar supplying regions, it is likely that caviar purveyors will start indicating the farmed origin of caviar even more clearly, especially for the European and Caspian species of sturgeon that are currently farmed in both the U.S. and Europe.

Most of the sturgeon meat is sold to distributors and the restaurant trade, although some of the major U.S. companies, such as Tsar Nicoulai, also sell smoked sturgeon products under their own label.

### Import and export statistics

In addition to the farmed and wild American and imported wild caviar sold in the U.S. market, farmed caviar produced in Europe and Urugway is also available to U.S. consumers (markyscaviar.com; Adler, 2006). Current reporting of U.S. trade statistics, however, is such that it does not allow distinctions between imports of wild and farmed caviar, making it difficult to determine actual amounts of farmed caviar imports.

The same holds true for caviar exports, although the availability of U.S. farmed caviar through international caviar purveyors such as Petrossian suggests that some of the U.S. farmed sturgeon products are exported along with U.S.-produced wild sturgeon and paddlefish roe.

Even though aggregate trade and consumption statistics for U.S. farmed caviar are currently not available, however, U.S. farmed caviar should be fairly distinguishable as an individual product on the market: It is either branded by the producing companies with a distinctive label or appears to be clearly identified in terms of its farmed origin, country origin, and species by luxury food purveyors who do not use the producer's own brand or who sell caviar from farms that do not brand their product.

With current CITES and U.S. bans on wild caviar trade and imports, respectively, it is to be expected that U.S. caviar imports will drop dramatically from the 74 tons reported for 2000 (Williamson, 2003), with U.S. wild and farmed caviar as well as imported farmed caviar filling some, if not all of the gap between caviar supply and demand.

International trade in sturgeon meat is similarly hard to track, since the sturgeon farms generally sell their meat to seafood distributors. Given the popularity of sturgeon meat in the U.S. (Mims et al., 2002), the fact that a possibly considerable portion of it goes to the restaurant trade (Van Eenennaam et al., 2004), as well as the fact that some or the largest sturgeon farming companies, such as California's Tsar Nicoulai, smoke some of their own meat and sell it directly through their websites, it is logical to presume that a significant portion of U.S.-produced farmed sturgeon meat is available in the U.S. market.

## Criterion 1: Use of marine resources

### Use of marine resources in sturgeon feed

All sturgeon species currently cultured in the U.S. are carnivores, and sturgeon reared in captivity have been found to perform best on diets high in fishmeal and fish oil (Ronyai and Varadi, 1995; Mims et al., 2002; Van Eenennaam et al., 2004).

Sturgeon farming therefore raises some of the broader ecological concerns associated with the farming of aquatic species situated high on the trophic ladder, most importantly, concerns about aquaculture-driven pressures on already overtaxed pelagic fisheries resources, and about the net loss of fish protein that tends to occur in the farming of many carnivorous fish species. These concerns are clearly elaborated in several pieces of important recent work, including Naylor et al., 1998; Naylor et al., 2000; Naylor et al., 2005; Weber, 2003 and will not be discussed in detail here.

Instead, this section will discuss the use of aquatic and marine resources specifically associated with the intensive farming of sturgeon. Relying on the broader context laid out by previous work, and using specific Seafood Watch criteria, it will then situate U.S. farmed sturgeon along a larger continuum that classifies cultured species based on the ratio of wild fish inputs to farmed fish outputs.

### ***Sturgeon feeds***

There is as yet no standard growout diet that is designed and used specifically for sturgeon (Van Eenennaam et al., 2004; Dr. Frank Chapman, Personal Communication; Dr. Terry Patterson, Personal Communication). U.S. aquaculturists have therefore been experimenting with diets containing different amounts of protein, ranging from 25 to 50% and 8-25% respectively (Van Eenennaam et al., 2004). Pelleted feeds with 35-45% of protein content and 12-16% lipids have been identified as generally suitable for growout (Ronyai and Varadi, 1995), and specific studies have reported 51% protein and 18% lipid to be optimal for growth of white sturgeon fingerlings.

In practice, commercially formulated trout feed is used by many sturgeon farming operations in the U.S., since the volumes of sturgeon culture are still too small to justify specialized feed formulations and production by feed manufacturers. Some of the larger sturgeon producers, both in the U.S. and Europe, however, are working with large feed manufacturers such as EWOS and Biomar towards the development of more specialized sturgeon feeds. As a result, both EWOS and Biomar are experimenting with feeds that take some of the known specifics of sturgeon nutritional requirements into account (Peter Struffenegger, Personal Communication; Shannon Crownover, Personal Communication; Biomar, 2005). Sturgeon culture practitioners, however, agree that even the more specialized feeds currently used are quite close in composition – including fishmeal and fish oil content - to commercial salmon and trout feeds (Dr. David Stephen, Personal Communication).

That being said, the exact amounts of fishmeal and fish oil in commercial salmon and trout diets are often hard to pin down, likely as a result of the proprietary nature of fish formulations (O'Neill, 2006). In a review of the culture of rainbow trout, however, Hardy et al. (2000) provide a generalized feed formulation for rainbow trout reared in freshwater aquaculture systems. According to their generalized formulation, fishmeal inclusion in farmed trout diets is about 33% and fish oil inclusion is about 18%. In addition, a BioMar document describing BioMar's sturgeon feeds specifies that these feeds can contain as little as 30 to 35% fish meal and 5 to 10% fish oil.

Finally, the product specifics provided on the label of the *EWOS Vita* feed used by some California sturgeon culture farms indicates a minimum protein content of 43% and a minimum crude fat content of 14%. Since some – unspecified in the producer's feed information – portion of the feed's protein, and possibly – of the feed's fat – comes from plant sources (Dr. David Stephen, Personal Communication), these label data are generally consistent with the rest of the available information on fishmeal and fish oil inclusion rates.

Consequently, an inclusion rate of 33% fishmeal in sturgeon feed is used here for the purposes of calculating the amount of marine resources that is used in sturgeon farming through sturgeon feeds.

Since greater differentials appear to exist among currently used sturgeon feeds with respect to their fish oil content, this report's calculations will use both an 18% fish oil estimate (consistent with the best available information on currently used trout feeds) and a 10% fish oil estimate reflecting currently available information on fish oil content in some of the emerging specialized sturgeon feeds.[9]

### *Notes on feed calculations*

In calculating total feed-related marine resource use by aquaculture, some researchers have added the fishmeal and fish oil inclusion rates together for a total inclusion rate and then used this figure in calculating the fish-in to fish-out ratio, but this fails to take into account that reduction fisheries are for both fishmeal and fish oil. In other words, the same fish are used to produce fishmeal and fish oil, so adding the inclusion rates together ignores the fact that they are products from the same fisheries and in effect double-counts the amount of wild fish inputs consumed. To avoid such double counting and to remain consistent with the methodology used in other Seafood Watch reports (see for ex. O'Neill, 2005; O'Neill, 2006), this report performs separate calculations for marine resource use through fishmeal and marine resource use through fish oil in sturgeon feed. It then uses the larger of the two numbers in assessing the fish-in to fish-out ratio for farmed sturgeon.

### *Feed conversion ratios*

The feed conversion ratio (FCR) – i.e. the ratio of feed inputs (dry weight) to farmed fish outputs (wet weight) - is a second statistic relevant to measuring the marine resource use involved in intensive sturgeon culture as currently practiced in the U.S. Given that many aspects of sturgeon nutrition are still in various stages of research and experimentation, there are no clearly established averages for sturgeon feed conversion, and/or clear differentiation between the FCRs observed for different sturgeon species under commercial culture.

Available data nonetheless provides just enough information to allow an estimate of cultured sturgeon FCRs for the purposes of this evaluation. Specifically, the FCRs for white sturgeon fed dried trout diet at a UC Davis experimental facility were estimated at 2.5:1 for fish in their third year of growth (Doroshov, 1985). That is, FCRs were estimated at 2.5:1 for fish that under commercial culture would be towards the final phase of growout for meat production in the case of males, and in the middle of the caviar production cycle, in the case of females. Mims et al. (2002) suggest FCRs between 1.6:1 and 2:1 for adult sturgeon (species is not specified, but the entire Mims et al., 2002 assessment is based mainly on the production of white sturgeon, so these numbers are either for white sturgeon, or some sort of an average across known species).

An FCR of 1.6:1 (that is 1.6 kg of feed input to 1 kg of farmed sturgeon output) is used for the purpose of this evaluation. This is the lower range of the FCR interval cited in the most recent scientific publication available (Mims et al., 2002), and also – an approximate FCR estimate that was offered by the science manager of one of the major California farms (Dr. David Stephen, Personal Communication).

---

[9] 10% fish oil content in feed is basically an estimate made on the basis of BioMar and EWOS feed information, as discussed in the text above. This estimate assumes, based on discussions with experts such as Dr. David Stephen, the manager of the Tsar Nicoulai sturgeon farm in California, that a portion of the 14% fat contained in the EWOS Vita feed comes from plant sources.

### *Yield rates*

A third statistic relevant to estimating sturgeon farming's use of marine resources through feed is the yield rate, which characterizes the efficiency of transforming wild fish from pelagic reduction fisheries into fishmeal and fish oil for use in feeds. Yield rates are measured as the ratio of wild pelagic fish used to the amount of fishmeal (or fish oil) generated from this wild fish in the process of reduction. They can vary based on the species of fish, the season, the condition of the fish, and the efficiency of the reduction plants (Tyedmers, 2000). A yield rate of 22% - or 4.5 kg of wild fish from reduction fisheries for each kilogram of fishmeal produced - is used for this report, since it is a rate that represents a good year-round average according to Tyedmers (2000). A fish oil yield rate of 12%, or 8.3 units of wild fish to produce 1 unit of fish oil, suggested by Tyedmers (2000) as a representative year-round average for Gulf of Mexico menhaden is also used. These rates are chosen as the most reliable average calculations currently available, although it is important to note that ongoing work tracking current dynamics of international fishmeal and fish oil production suggests that fishmeal and fish oil yields may be actually lower than the ones estimated by Tyedmers and used here.

### *Ratio of wild fish input to farmed sturgeon produced by aquaculture operations*

Based on the numbers above, the following calculations provide an estimate of the wild fish input to farmed fish output for U.S. farmed sturgeon:

Conversion for fishmeal:

Based on a fishmeal inclusion of 33%, applicable across the trout and other feeds currently used by sturgeon farmers in Idaho, Florida, and California

$$\frac{4.5\text{ kg wild fish}}{1\text{ kg fishmeal}} \times \frac{0.33\text{ kg fishmeal}}{1\text{ kg sturg. feed}} \times \frac{1.6\text{ kg feed}}{1\text{ kg frmd sturg.}} = \textbf{2.38 kg wild fish/kg farmed sturg.}$$

Conversions for fish oil

a) Based on fish oil inclusion of 18%, as estimated for the trout feed used by Florida and Idaho sturgeon farms

$$\frac{8.3\text{ kg wild fish}}{1\text{ kg fishmeal}} \times \frac{0.18\text{ kg fishmeal}}{1\text{ kg sturg. feed}} \times \frac{1.6\text{ kg feed}}{1\text{ kg frmd sturg.}} = \textbf{2.39 kg wild fish/kg farmed sturg.}$$

b) Based on fish oil inclusion of 10%, as estimated for the more specialized sturgeon feed used by California farms

$$\frac{8.3\text{ kg wild fish}}{1\text{ kg fishmeal}} \times \frac{0.10\text{ kg fishmeal}}{1\text{ kg sturg. feed}} \times \frac{1.6\text{ kg feed}}{1\text{ kg frmd sturg.}} = \textbf{1.32 kg wild fish/kg farmed sturg.}$$

As noted above, the numbers for marine resource use through fishmeal and marine resource use through fish oil are not added together, as that would result in double-counting the wild fish inputs required to grow the farmed fish (since the same wild fish are generally reduced to both fishmeal and fish oil). Instead, the larger of the two numbers is taken to represent the ratio of wild fish input to farmed sturgeon output.

In the case of Florida and Idaho sturgeon that is currently fed commercial trout feed, the application of this methodology to the above calculations indicates that it takes 2.39 pounds of wild fish to produce 1 pound of farmed sturgeon. In the case of California farmed sturgeon, which is fed somewhat specialized sturgeon feed, the relevant estimates and calculations suggest that it takes 2.38 pounds of wild fish to produce 1 pound of farmed sturgeon.

In practice, the wild fish input: farmed fish output ratios for California sturgeon on the one hand and Idaho and Florida sturgeon on the other are so close that we can generalize a ratio of 2.4 for U.S. farmed sturgeon over-all. That is, based on the best available data, we can conclude that it currently takes 2.4 kilograms of wild fish to produce a kilogram of farmed sturgeon in U.S. sturgeon culture facilities.

It is important to note that recent experimental work on sturgeon diets suggests the viability of sturgeon feeds with as little as 6% fishmeal (Dr. Frank Chapman, Personal Communication). Consequently, while the above calculations represent the best estimates given currently available data, re-calculations of sturgeon farming's use of marine resources through feed will be called for when changes in feed formulations and husbandry practices bring about lower fishmeal and fish oil use in feed and/or higher feed conversion ratios by farmed sturgeon.

### Broodstock

All commercial sturgeon culture facilities currently in operation rely on domesticated broodstock, with some of the facilities using their own broodstock, while others rely on the purchase of fry produced by facilities with hatchery operations. While the reproductive cycle for both white sturgeon and the several European species cultured in Florida has now been closed in captivity, research and experimental work continues on various aspects relevant to the domestication of sturgeon, including research on the growth, sexual maturation, fecundity, and gamete quality of captive sturgeon broodstocks, on management practices that can improve the reproduction, growth, and health of domestic sturgeon broodstock, and on the genetic inheritance of important traits.

No wild broodstock collection is occurring in any significant numbers for any of the U.S. farmed sturgeon species covered in this report. At least one of the California farms – Tsar Nicoulai – is currently taking a few wild broodstock for spawning each year in addition to using its captive-reared broodstock. These broodstock are returned to the wild following egg and milt collection to be used in artificial sturgeon reproduction. The continued reliance on some wild broodstock is used as a measure to ensure the continuing genetic diversity of the farm's sturgeon. The farm has a permit to take wild sturgeon from the California Department of Fish and Game (Cliff, 2005; Dr. David Stephen, Tsar Nicoulai, Personal Communication). Other California farms that have their own on-site hatchery operations can also obtain permits for taking a limited number of wild fish for spawning, although they are not availing themselves of this opportunity at the present time: based on advice from UC Davis researchers with whom the farmers collaborate, these farms do not consider the collection of wild broodstock to be currently necessary for maintaining the genetic diversity of their captive stock (Peter Struffenegger, Personal Communication). Florida farms, which focus on the cultivation of non-native species of threatened status are reported to be self-sufficient in terms of their broodstock (Dr. Frank Chapman, Personal Communication).

**Synthesis**

Farmed sturgeon diets contain fishmeal and fish oil that are sourced from wild fisheries (BioMar 2005; O'Neill, 2006). Under current feeding practices, inclusion levels of fishmeal and oil in the diets of many U.S. farmed sturgeon reflect the inclusion rates in commercial trout diets and remain in the 30% range and 10-18% range for fishmeal and oil respectively. These inclusion rates are high compared to those of other aquaculture species, such as hybrid striped bass or tilapia.[10] The exact provenance of the pelagic fish whose reduction provides the fishmeal and oil used in sturgeon feeds cannot be reliably determined on the basis of available data. Therefore, little can be currently said about the stock status of the reduction fisheries used in the production of the fishmeal and oil incorporated in sturgeon feeds.

Under current diets and feed conversion ratios, however, the overall ratio of wild fish used as feed to farmed fish produced is 2.4. Therefore, although the propagation practices used by U.S. sturgeon farms, all of which are largely reliant on domesticated broodstock, clearly do not result in any negative impacts on brood stock, wild juveniles or associated non-target organisms, the high ratio of wild fish input to farmed sturgeon output currently puts farmed sturgeon in a category of high marine resource use by Seafood Watch criteria.

With much of sturgeon nutrition and sturgeon feeds still in a research and development phase, it is yet to be seen where the development of specialized sturgeon feeds will lead in the future; that is, whether new developments in nutrition and feed formulations will lead to the decrease in the use of fish protein in favor of plant proteins, or whether fishmeal and oil use will remain relatively constant over time.

**Use of marine resources rank:**

Low 🟩 Moderate 🟨 [✓ High 🟥]

## Criterion 2: Risks of escaped fish to wild stocks

Aquaculture is now firmly established as one of the most significant vectors for nonindigenous species transfer and introduction (Rosenfeld and Mann, 1992; Carlton, 1992; 2001; Naylor et al., 2001).

---

[10] See detailed Seafood Watch reports on these species at http://www.mbayaq.org/cr/SeafoodWatch/web/sfw_factsheet.aspx

Generally, the consequences of nonindigenous species introductions can take the form of competition, predation, introduction of new diseases, alteration of ecosystem structure and function, and genetic impacts through interbreeding or hybridization (Carlton, 1993; 2001; Myrick, 2002; Lightner et al., 1992).

Introduction of non-native sturgeon species or genetically different strains of native species is considered to have a significant potential for impact on wild sturgeon stocks through competition and hybridization (Williamson, 2006, p. 211). Hybridization in particular is an important concern in the case of sturgeon, since both natural and artificially induced hybridization between different sturgeon species is well known and clearly documented, with many of the resulting hybrids (such as the bester hybrid, a cross between beluga, *Huso huso*, and sterlet, *Acipenser ruthenus*) being reproductively viable (Doroshov, 1985; Ronyai and Varadi, 1995; Williamson, 2003).

In Europe, where sturgeon are cultured in tanks, raceways, and increasingly – in ponds, and where cultured sturgeon goes not only to human consumption, but also to aquarium and garden pond use and to the recreational fishing market (Willot et al., 2001), experience points to escapes of non-native sturgeon and to possible hybridizations occurring as a result of such escapes (Arndt et al., 2002; FIRI, 2005). For example, an analysis of sturgeon catches made between 1981 and 2000 in German, Polish, and Dutch coastal waters and tributaries revealed a significant decline in the endemic European sturgeon (*Acipenser sturio*) over the survey period, and a drastic increase in total catches of nonindigenous sturgeon species that are intensively cultured in Germany and neighboring countries and/or used in aquaria and in the pet trade. Siberian sturgeon (*Acipenser baeri*), white sturgeon (*Acipenser transmontanus*) and Russian sturgeon (*Acipenser gueldtaedti*) were among the nonindigenous sturgeon species found in German, Polish, and Dutch coastal waters (Arndt et al., 2002). The same analysis also discovered the presence of unidentified hybrids in the studied catch (Arndt et al., 2002). Aquaculture-caused introductions of nonindigenous sturgeon in Europe are reported to be the result of technical malfunctions in production facilities (Arndt et al., 2002), but no further details on escape specifics could be found in the literature, except that aquarists, rather than aquaculture facilities, are considered responsible for the majority of exotic sturgeon releases in European waters.

In general, the nature of U.S. sturgeon culture facilities – land-based tanks and raceways, rather than open water netpens or direct stocking of natural water bodies – increases the over-all capacity for farmed fish containment and lowers the overall risk of farmed sturgeon escapes.

Idaho raceway systems, which operate on a flow-through principle and discharge directly to natural water bodies, prevent escapes through the use of screens, which are installed at raceway inlets and outlets, and sized according to the age and so size of fish stocked in individual raceways. The screens are inspected by the Idaho Department of Agriculture, the state aquaculture licensing authority, during farm visits that are a routine part of the licensing process. In addition the new draft EPA NPDES permits will require regular inspection of physical structures (i.e., raceways, screens, inlets, etc.) to minimize the possibility of structural failure (Gary Fornshell, Personal Communication).

In California, tank systems for the culture of white sturgeon are installed on land, often at some distance from surface water bodies. Effluent discharges can connect tank-based farms to natural water bodies, but this connection is often indirect, for example through discharge to irrigation canals. Appropriate size screens are used in culture tanks to prevent escapes of the smaller juvenile fish, while the large size of adults eventually obviates the need for such screens. The likelihood of survival in the event of any escapes from such tank systems is considered minimal (Dr. Serge Doroshov, Personal Communication).

Most importantly, however, both California and Idaho farms rear strains of white sturgeon native to the regions where the farms are located – the Sacramento-San Joaquin river and delta in the case of California, and the Snake River in the case of Idaho **(**Dr. Serge Doroshov, Personal communication; Dr. Terry Patterson, Personal communication). In fact, some of the same sturgeon that were spawned for commercial culture in Idaho facilities were also used as part of a state FWS white sturgeon re-stocking program in the Snake River (Dr. Terry Patterson, Personal Communication).

Finally, California white sturgeon and Idaho Snake River sturgeon populations, although vulnerable as a result of considerable habitat loss and related pressures, are considered to be at lower risk than most other North American sturgeon species and populations. This is the case under both Endangered Species Act and IUCN Red List criteria (McDougall, 2005; IUCN Sturgeon Specialist Group, 2004).

Consequently, sturgeon farming in California and Idaho, as it is currently practiced, poses low risks to wild sturgeon stocks as far as farmed fish escapes are concerned.

Florida sturgeon culture, on the other hand, presents a somewhat different situation, since it is based on the tank culture of non-native species in a context where all three of the native sturgeon species –Atlantic, Gulf, and Shortnose sturgeon - are considered vulnerable, threatened, or endangered, respectively, under ESA criteria (McDougall, 2005), and where no exotic sturgeons have been previously introduced to native sturgeon habitats.

Given that unless an aquatic species is one of the few listed as injurious under the federal Lacey Act or the federal Noxious Weed Act, it is generally up to the states to decide whether an exotic species can be imported for use in aquaculture or other economic activities, and given that very many exotic aquatic species are imported, cultured, and traded in the U.S., the use of exotic species in Florida sturgeon culture is not surprising in and of itself.

The decision to go ahead with the culture of several non-native sturgeon species was, however, made following sturgeon culture risk assessment process conducted by the state in 1999-2000. The process, which involved input from a range of academic scientists, government agencies, and aquaculture industry and was conducted by the Florida Department of Agriculture and Consumer Services, examined a range of ecological risks associated with the culture of both native and nonindigenous sturgeon in Florida. Ecological concerns associated with the culture of nonnative species that were raised and examined in the process included the risks of non-native species escapes and hybridization. A number of ecological concerns were also raised with respect to the culture of sturgeon species native to Florida waters, most prominent among them concerns about the ecological impacts of acquiring native broodstock for culture.

Insights and recommendations that came out of the 1999-2000 Florida sturgeon culture risk assessment process were incorporated in the development of Florida's Best Management Practices for aquaculture,  through which the Florida Department of Agriculture and Consumer Services (DACS) currently regulates all aquaculture in the state.

Under these BMPs, Florida sturgeon culture operations, which culture non-native sturgeon exclusively, are expected to have all of their holding, transport, and culture systems be designed to prevent the release of such non-native sturgeon into waters of the state. To that end, the BMPs call for a range of biosecurity practices, such as avoidance of facility location inside the 100-year flood zone; or if in the zone – elevation of any outside (non-enclosed) portion of the facility at least a foot above the 100-year flood elevation. Biosecurity practices called for in the BMPs also include including zero-discharge production systems, or otherwise - the implementation of redundant containment and disinfection procedures such as combinations of physical barriers to prevent the escape of all life stages of sturgeon and chemical or UV sterilization of discharge; the use of covered tanks or ponds for all fish containing fish weighing less than 4lbs, and predator stocked detention ponds (DACS, 2005).

According to Dr. Frank Chapman of the University of Florida, Gainesville, all current Florida sturgeon culture operations are zero-discharge systems, with all non-enclosed portions of the aquaculture facilities situated a foot or more above the 100-year flood elevation. He also reports that no fish escapes have occurred from these Florida facilities to date, in spite of the fact that they recently (2005) weathered three hurricanes. The hurricanes cause no major damage or any loss of fish in spite of, among other disruptions, prolonged power outages that lasted about 15 days (Dr. Frank Chapman, Personal communication).

Sturgeon culture facilities in Florida are subject to regular monitoring and enforcement by the Florida Department of Agriculture and Consumer Services under its Best Management Practices authority (Hill, 2006; Dr. Frank Chapman, Personal communication).

### Synthesis

Given the biology and natural history of sturgeons, there are real risks associated with the potential escape of non-native farmed sturgeon into habitats of wild North American sturgeon. Competition, hybridization, and genetic dilution are among the most serious of these risks. Applying the relevant seafood watch criteria to the evaluation of escape risks and escape management practices that are currently used in U.S. sturgeon culture facilities, however, suggests that the actual risks posed by farm escapes to wild sturgeon stocks should be low for all sturgeon culture regions and across U.S. sturgeon culture facilities.

At the same time, given that U.S. sturgeon culture is currently poised for expansion, particular attention needs to be paid to future developments, including the choice of species and farming systems, as well as the choice and application of on-farm management practices. Particular care should also be exercised to continue the application of good management and containment practices as the volume of sturgeon culture expands in existing and new sturgeon culture facilities.

**Risk of escaped fish to wild stocks rank:**

[✓ Low 🟩] Moderate 🟨 High 🟥

## Criterion 3: Risk of disease and parasite transfer to wild stocks

Past experience shows that the aquaculture-mediated introduction and on-farm amplification of parasitic, bacterial or viral diseases of aquatic organisms is a distinct concern. So are the transmission or re-transmission of diseases from farmed to wild organisms (Blazer and LaPatra, 2002; Paone, 2000; Carr and Whoriskey, 2004; Krkosek et al., 2005; Krkosek et al., 2006).

The greatest risks for contamination of wild fish by farmed animals are associated with open culture systems such as net pens. On-land facilities such as tanks and raceways, however, carry disease transfer risks as well, unless they are operated as completely closed systems with no discharges to or in the vicinity of natural waterways. Tank and raceway systems considerably reduce the opportunity for direct contact between farm and wild animals, but effluents from tank and raceway facilities are generally only treated for organics and particulates, and can therefore still contain disease agents when they leave the farm. In cases where such potentially contaminated effluents are either directly, as in sturgeon raceways in Idaho, or indirectly, as in the case of some California tank culture operations, discharged into native sturgeon watersheds, there is a risk of disease transmission. A further risk of disease transmission is associated with the potential escape of infected farmed animals which can transmit the disease to wild fish through direct contact.

Where the sturgeon farmed in intensive aquaculture facilities is native to the region in which farming occurs, with farmed animals generally only a few generations removed from the wild stock - such as is currently the case with California and Idaho sturgeon culture - it is logical to expect that the greatest disease risks posed by farmed fish to their wild counterparts will stem from the amplification and re-transmission of diseases that are already endemic in wild populations. Some possibility for infection of farmed fish with novel diseases not endemic to their wild counterparts, and of a subsequent transmission of such novel diseases to wild fish is also present, however. For example, native fish farmed in a particular aquaculture facility can become infected with a novel disease after contact with fish brought from a different facility that combines the culture of various species; the infected farmed fish can then transmit the new disease to wild populations through farm effluents or through the escape of infected farmed fish.

Where non-native sturgeon species are farmed in the vicinity of native sturgeon habitats, such as is currently the case of Florida, there is a theoretical risk of infecting native sturgeon populations with novel diseases originating in the farmed stocks. In practice, however, the magnitude of this risk depends on the type of culture system, the level of containment for farmed fish and farm effluents, and the actual disease status of farmed fish.

### *Diseases of cultured sturgeon*

Current knowledge points to several viral, ectoparasitic, and fungal diseases occurring in cultured sturgeon. Of greatest concern and greatest potential for damage and mortalities are viral diseases, which include white sturgeon irridiovirus (WSIV) and two types herpes viruses (LaPatra et al., 1994; Georgiadis et al., 2000; Georgiadis et al., 2001; Kwak et al., 2006; Dr. Ronald Hedrick, Personal Communication).

Both white sturgeon irridiovirus and white sturgeon herpes viruses affect sturgeon in its early life stages (LaPatra et al., 1994; Georgiadis et al., 2000; Georgiadis et al., 2001; Drennan et al., 2005). Juvenile white sturgeon infected with WSIV have been found to become lethargic, cease feeding, get emaciated, and linger at the bottom of the culture tank (Hedrick et al., 1990, 1992; Watson et al., 1998 cited in Kwak et al., 2006). In contrast to WSIV, fish infected with a herpesvirus may not be emaciated, although clinical signs are not always reliable way to differentiate between the two types of infection (Georgiadis et al., 2001). White sturgeon irridiovirus mortality on farms can approach 95% for affected groups of juvenile fish (Hedrick et al., 1990; 1992 cited in Georgiadis et al., 2001).

WSIV is among the more difficult fish irridioviruses to isolate in cell culture, but new diagnostic tools, such as Polymerase Chain Reaction (PCR) assays aimed at early detection of WSIV DNA in white sturgeon tissues, and so at more effective management of WSIV infections among farmed juvenile populations are being currently developed and tested (Kwak et al., 2006).

Reflecting a familiar dynamic where less is known about the distribution and frequency of diseases in wild fish populations than their farmed counterparts (Blazer and LaPatra 2002; O'Neill, 2005), WSIV was first discovered in cultured white sturgeon in California in 1988 (Hedrick et al., 1990 cited in LaPatra et al., 1994).

Both irridiovirus and herpesviruses are considered endemic in wild Northwest populations of white sturgeon (LaPatra et al., 1994; Georgiadis et al., 2001; LaPatra et al., 1999 cited in Drennan et al., 2005; Dr. Ronald Hedrick, Personal Communication). Existing knowledge also suggests that the most likely pathway for viral infection is through vertical transmission from broodstock to progeny (Georgiadis et al., 2001). The fact that many of the captive broodstock currently used in aquaculture operations are survivors of both WSIV and herpes viruses is therefore considered responsible for the viral disease outbreaks that periodically affect all white sturgeon culture facilities (Dr. Ronald Hedrick, Personal Communication).

Direct contact between infected and uninfected fish is another cause of viral disease transmission in sturgeon, although this type of transmission is considered most likely if contact is accompanied by the simultaneous occurrence of a stressful event (Georgiadis et al., 2001). Finally, tank-to-tank transmission of a WSIV infection, through water, is known to be a possible pathway for the transfer of viral diseases within a culture facility, but such tank-to-tank transmission through culture water is considered to be less likely than vertical transmission and transmission through contact (Georgiadis et al., 2001).

Excessive handling, transport stress, poor water quality, decreased flow rates and high-density rearing have all been identified as stressors conducive to outbreak events resulting in major mortality (Georgiadis et al., 2001; Drennan et al., 2005). Management practices that minimize the exposure of cultured sturgeon to such stressors – e.g. sustaining low fish densities and loadings, maintaining virus-free water supplies, minimizing adverse environmental conditions, and reducing the handling of sturgeon younger than 1 year – are, in turn, capable of minimizing WSIV outbreaks even for cultured animals in which infection is present (LaPatra et al., 1994; Georgiadis et al., 2000; Georgiadis et al., 2001; Drennan et al., 2005).

These dynamics, in combination with the fact that many farmed sturgeon are infected with white sturgeon irridiovirus - the likely result of infected broodstock and a vertical transmission of the virus, suggest the importance of applying management practices that minimize stress for farmed animals, including lower stocking densities, avoiding exposure to adverse environmental conditions (e.g. low oxygen, high temperatures), and minimizing the handling of young sturgeon. Such practices are applied by all sturgeon culture facilities currently in operation as a principal measure for the prevention of disease outbreaks.

Although present, ectoparasitic and fungal diseases are not considered a major threat to cultured white sturgeon, and are successfully managed through a combination of regular maintenance and the culture facilities and the application of mild disinfectants such as hydrogen peroxide and potassium permanganate (Dr. Ronald Hedrick, Personal Communication).

Since all sturgeon cultured in Florida is non-native, these sturgeon were initially imported. The Florida Aquaculture BMPs require that all imports of live sturgeon be accompanied by a signed "Certificate of Health" attesting to the good health of the sturgeon

At the same time, leading experts on sturgeon diseases have expressed serious concern regarding the disease status of exotic sturgeons being imported in the U.S. for culture, citing the difficulty and general lack of present capacity to guarantee that such species are free from disease. Specifically, experts have suggested that based on their experience, it is unlikely that foreign-origin sturgeon had been examined for the presence of viral agents, and that health certificates or other claims of freedom from viral agents for imported sturgeon are therefore of little value (Hedrick, 1999).

The Florida BMPs for sturgeon culture also require culture facilities to notify their aquatic animal health professional of the Florida Department of Aquaculture and Consumer Services, Division of Animal Industries, State Veterinarian's office if diseases or other suspected pathogens are observed in cultured stock, and before disposing of any sturgeon that manifest symptoms of the disease (Florida Department of Aquaculture and Consumer Services, 2005).

Such reporting seems to so far indicate that unlike their white sturgeon counterparts, the five nonindigenous species currently cultured in Florida have not been known to be affected with viral disease. Most bacterial and fungal diseases known to affect wild sturgeon species in Europe and Russia, have also reportedly not been observed in Florida stocks so far (Dr. Frank Chapman, Personal Comunication).

### *Risk of disease and parasite transfer to wild stock*

In the case of white sturgeon farming, the possibility of viral disease transfer through direct contact between infected and uninfected fish suggests the presence of distinct risks to wild sturgeon populations from any escapes of infected farmed sturgeon. Such farmed-to-wild disease transfer risk is especially the case in a context where many farm fish are carriers of viral infections, where actual disease outbreaks are triggered by stressful events, and where the occurrence of stressful events and conditions cannot be controlled for wild sturgeon populations.

The use of escape prevention systems by all U.S. sturgeon culture facilities should, however, considerably reduce the likelihood of occurrence of a direct contact between farmed and wild fish.

Farm effluent, however – in cases such as California and Idaho farms where such effluent is discharged to the outside environment - remains a possible pathway for disease transmission from farmed to wild sturgeon (Dr. Ronald Hedrick, Personal Communication), and such farm effluents are not presently managed with disease risks in mind.

At the same time, current research shows that the probability of water-mediated, tank-to-tank transmission of viral infections is lower than the risks of vertical transmission from broodstock to progeny or direct transmission through contact between infected and uninfected fish (Georgiadis et al. 2001), thereby suggesting that the risks of effluent-mediated transmission of sturgeon viral diseases are lower than the disease transmission risks associated with other pathways.

Currently, the prevalence of viral diseases in wild populations remains unknown (Dr. Ronald Hedrick, Personal Communication), and there is no evidence of sturgeon disease amplification and re-transmission to have occurred as a result of sturgeon culture operations in general and their effluent discharges in particular.

In Florida sturgeon culture facilities, which focus on nonindigenous species, escapes are, as discussed in the previous section, reported to be successfully prevented through the use of biosecurity measures as specified by the Best Management Practices of the Department of Agriculture and Consumer Services. It is, however, the case, that the actual disease status of Florida non-native sturgeon stocks remains undetermined, with the general absence of disease outbreaks so far being insufficient evidence to conclude freedom of the cultured stock from diseases and pathogens – particularly so in a context where the leading experts on sturgeon disease suggest that little is known or can be meaningfully said about the level of infection among Florida’s nonindigenous fish. This fact, in combination of the fact that Florida BMPs allow for effluent discharges from sturgeon culture facilities suggests that distinct disease transmission risks exist, in spite of the fact that their specific nature and magnitude remain unknown as a result of the absence of any scrutiny.

### Synthesis

In the case of California and Idaho sturgeon farms, the main viral diseases of white sturgeon – including irridiovirus and herpesvirus – are endemic to wild sturgeon populations. The research on sturgeon diseases, however, has so far focused on the occurrence, management and prevention of diseases in farmed sturgeon. To date, there is little knowledge on the prevalence of disease in wild populations. There is also no evidence of disease outbreaks in wild sturgeon being caused by infected farmed animals, although stressful farming conditions are known to have triggered some viral disease outbreaks in cultured fish, and although actual and potential pathways for farmed-to-wild disease transfer do exist in the form of sturgeon farm effluents and escapes, respectively.

In the case of California and Idaho white sturgeon farms, we therefore have a situation where there is absence of evidence for farmed-to-wild disease transfer, yet where such absence of evidence does not constitute evidence of absence of such transfers. On-farm amplification and re-transmission of disease remains a possibility.

Florida farms, which are focused on the culture of several exotic species, are so far reported to have experienced few disease outbreaks. Many of the diseases known to afflict wild [and farmed?] sturgeon of the species cultured in Florida have thus far not been observed in farmed Florida stocks, although farmed sturgeon could still be the carriers of disease, thereby creating the potential of future outbreaks. Since pond culture, and non-zero discharge culture of such nonindigenous sturgeon is currently allowed in Florida under the state's aquaculture Best Management Practices, a risk of on-farm amplification and transmission to wild fish does exist, even if at present only on theoretical grounds.

Finally, the stock status of native white sturgeon in the California and Idaho regions where white sturgeon is farmed is considered vulnerable, with both California and Idaho Snake River sturgeon stocks closed to commercial fishing. Native Atlantic, gulf, and shortnose sturgeon in Florida are even more vulnerable and currently under various levels of federal Endangered Species Act protection.

Consequently, in applying the relevant criteria, this report classifies the overall risks of disease and parasite transfer from farmed to wild sturgeon stocks as moderate for California and Idaho white sturgeon facilities, as well as for Florida farms rearing exotic sturgeon.

**Risk of disease transfer to wild stocks rank:**

<u>California and Idaho native white sturgeon culture</u>

Low 🟩 [✓ Moderate 🟨] High 🟥

<u>Florida culture of nonindigenous sturgeon species</u>

Low 🟩 [✓ Moderate 🟨] High 🟥

## Criterion 4: Risk of pollution and habitat effects

Aquaculture pollution is generally caused by a combination of nutrients, suspended solids, and chemicals that occur as by-products of the rearing process (O'Neill, 2006), with the majority of aquaculture wastes usually coming from excretion and excess feed (Beveridge, 1996). The potential for ecological impact from aquaculture wastes depends, considerably, on the type of culture system used. Intensive systems, especially those that are open to natural bodies of water, have the greatest potential for polluting the environment, while there is little potential impact from closed or semi-closed systems in which discharges are infrequent and wastes can be treated and disposed of (Costa-Pierce 1996).

Like all types of animal husbandry, the aquaculture of sturgeon is a source of wastes whose release into the environment can be the potential cause of ecological damage. An evaluation of the types of culture systems, water treatments, and effluent management practices currently used in U.S. sturgeon culture, however, indicate that sturgeon farm effluents are not a source of environmental concern at the present time. The general absence from U.S. sturgeon culture of any but the mildest chemical treatments, such as hydrogen peroxide and potassium permanganate, further contributes to this status.

Conversations with culturists seem to indicate that they are particularly conscious of avoiding the use of any feed in excess of the actual nutritional requirements of the fish, a [management] practice which also translates into minimizing the nutrient content of the farm water that is to be treated and/or discharged, since there is no excess feed dissolving and/or decomposing in the system to create extra nutrients (Dr. David Stephen, Personal Communication).

The two types of production systems used in U.S. sturgeon culture are tanks and raceways, with each type of system employing a somewhat different approach to the treatment and discharge of effluents.

Flow-through raceway systems are the method currently used in Idaho sturgeon culture. Idaho sturgeon raceways are the same raceways as those used in the state's trout culture, and in fact, sturgeon farming in Idaho takes place alongside trout farming, within some of the same companies and facilities. Idaho sturgeon raceways apply the same water treatment and effluent management practices that are used in trout raceway culture (Gary Fornshell, Personal communication). This means that water for the sturgeon raceways is diverted from springs, streams or artesian wells, and settling basins are used to remove solids and solids-bound nutrients prior to discharging the water from the culture facility back into nearby streams (Hinshaw et al., 2004). Sludge from settling basins is land-applied as fertilizer for crops or through composting (Hinshaw et al., 2004; Gary Fornshell, Personal Communication). High volumes of effluent are generally discharged from flow-through aquaculture facilities, but these effluents have been determined to contain low concentrations of pollutants (O'Neill, 2006).

Current tank-based sturgeon farming operations derive their water from underground wells and rely on drum filters to treat water that has gone through the culture system. Most of the companies currently in operation re-circulate the original ground water once or more through their system prior to discharging it to the outside environment. Some tank farms practice close to zero discharge.

California's Tsar Nicoulai company, for example, which is one of the largest U.S. producers, relies on repeated recirculation, with minimal discharges to the outside environment, mostly from the purification tanks in which fish are kept for a period of time prior to slaughter (Dr. David Stephen, Personal Communication). The Tsar Nicoulai farm treats its culture water through a combination of filtration, natural biological processes and aquaponic uptake of nutrients by water hyacinth. The integrated treatment system is used together with reservoir ponds, allowing complete water re-use. Periodic recharges of the culture facilities with water from the source wells are therefore mostly needed to compensate for water loss through evaporation (Cliff, 2005; Dr. David Stephen, Personal Communication).

Other California companies rely on tank culture for its production also recirculate their water once or more before it discharges it, using drum filters for water treatments, and discharging to a reclamation district, with some of the discharged water going through wetlands and some directly used for irrigation.

Intensive water use is a source of special environmental concern in the California and Idaho areas where sturgeon is currently farmed, but given the nature of sturgeon farming practices, sturgeon culture is not a consumptive use of water in some states, such as Idaho, aquaculture is a non-consumptive use by law), and so does not contribute to larger problems of water overuse and/or shortage. Both in itself and in comparison to other agricultural and aquacultural activities, the amounts of land needed for sturgeon farming are very small. Such farming is currently taking place in regions that are already developed for agricultural and residential use. In California, some of the sturgeon farms are actually located on historically agricultural land that is increasingly lost to residential development.

**Synthesis**

The combination of culture systems, water treatment and effluent management practices used by both types of U.S. sturgeon culture facilities, as well as the limited use of only mild chemotherapeutants in sturgeon culture, U.S. sturgeon farming poses a low risk to the environment through pollution and habitat effects.

**Risk of pollution and habitat effects rank:**

Raceway culture systems (Idaho)

[✓ Low 🟩] Moderate 🟨 High 🟥

### Tank culture systems (California and Florida)

[✓ Low 🟩] Moderate 🟨 High 🟥

## Criterion 5: Effectiveness of the management regime

Like most types of U.S. aquaculture, sturgeon culture falls under the purview of numerous federal and state laws and regulations, with a range of federal and state agencies involved in the permitting and monitoring of various aspects of culture operations. The available data suggests that, unlike many other types of aquaculture, the commercial culture of sturgeon is fairly well managed, both in terms of the nature and coverage of the relevant laws and regulations and in terms of how these laws and regulations are applied in on-the ground regulatory and management practice.

Permits for water use, the commercial rearing of fish, the use of any wild broodstock for spawning, as well as the importation of any non-indigenous species are among key aspects of sturgeon culture that are usually controlled at the state level. Effluent discharges, the use of therapeutants, and predator control are aspects generally controlled under federal statutes, although numerous and sometimes complex interactions between federal and state agencies and statutory authorities occur in the regulation and monitoring of various environmental aspects of aquaculture activities.

The control of effluent discharges from aquaculture – a key aspect of the current U.S. aquaculture management regime – is done under the Federal Clean Water Act's National Pollution Discharge Elimination System (NPDES). The NPDES system is specifically designed to control discharges of pollutants from point sources – a category that includes most aquaculture facilities - to waters of the U.S. Requirements in the NPDES permits of individual sturgeon culture facilities may vary somewhat, but most are based on general effluent limitation guidelines for aquaculture that were recently established by EPA.[11] The NPDES permits required for individual aquaculture facilities are issued either directly by the EPA, as is the case in Idaho, or by state agencies to which EPA has delegated the responsibility for administering the NPDES

---

[11] Since these EPA effluent limitation guidelines apply to facilities that produce, hold, or maintain at least 100,000 pounds a year in flow-through or re-circulating systems and discharge wastewater at least 30 days a year, they should apply to most current sturgeon culture facilities, although it is possible that some of the smaller facilities do not reach the specified volume – since production volumes were treated as proprietary information by many producers, and therefore hard to pin down for each individual facility, although most major California and Idaho facilities are estimated to have the necessary volume based on the available information. In the case of Idaho, for example, sturgeon culture facilities fall under the EPA aquaculture effluent guidelines although the volume of sturgeon cultured may be under 100 000 lbs, since sturgeon is cultured alongside large numbers of trout in the same facilities. The California tank culture systems, on the other hand, are generally large, with volume estimated to pass the EPA-specified threshold.

program. In California, NPDES permits are issued by the Regional Water Quality Control Boards, and in Florida - by the Department of Environmental Protection.

NPDES permits are subject to compliance monitoring, as well as to periodic review and renewal. Such review and renewal usually occurs once every five years.

Another key aspect of aquaculture activities that is controlled at the federal level is the use of drugs and medicated feeds. Currently, however, few therapeutants are used in sturgeon culture since there are no therapeutants that are known to be useful against the viral diseases that are currently the most important health concern is sturgeon culture. Consequently, fish health in sturgeon culture is primarily managed through the systematic reduction of stress, especially for the more susceptible juveniles, and this management has been largely successful to date.

The U.S. Fish and Wildlife Service (USFWS) has regulatory authority over aquaculture under several statutes. The Lacey Act puts US FWS in control of the importation and interstate shipment of wild animals, including fishes and their offspring and eggs, that are either listed in the Act or determined by the Secretary of the Interior to be injurious to people, forestry, agriculture or wildlife. Lacey Act regulatory authority has not been so far deemed relevant to, or exercised with respect to sturgeon culture by US FWS.

The U.S. Fish and Wildlife Service also has aquaculture-relevant authorities under the Federal Endangered Species Act. The FWS has exercised this ESA authority to prohibit the aquaculture of native sturgeon species in Florida – a prohibition aimed at protecting gulf sturgeon, which is listed as threatened under the act, shortnose sturgeon, which is listed as endangered, and Atlantic sturgeon, which is currently under review for ESA listing.

As of October 21, 2004, the US FWS has also listed beluga sturgeon as threatened under the Endangered Species Act. Given the continued evidence of ongoing gaps and deficiencies in the management of beluga populations in their native range, the ESA listing has been accompanied by a ban on the imports and trade in beluga caviar and other beluga products. This trade ban is intended to remain in place until there is evidence of improvement in the conservation measures for beluga in the Caspian and the rest of its native range.

The meat and caviar of beluga sturgeon farmed in U.S. can, however, be exempted from the current trade ban. To receive a FWS exemption, U.S. beluga culture facilities, such as those currently operating in Florida, have to submit a written request to the USFWS, and provide the Division of Scientific Authority evidence that they are using appropriate BMPs to prevent the escape of fish and pathogens. To get an exemption from the beluga trade ban, U.S. culture facilities have to also show that they do not rely on wild beluga sturgeon for broodstock, and provide the FWS with evidence that they have entered formal agreements with one or more native range countries to study, protect, or otherwise enhance the survival of wild beluga sturgeon. The US FWS trade exemptions do not apply to trade (import, export, re-export, or interstate and foreign commerce) in live beluga sturgeon, and may be revoked at any time if the USFWS determines that any of the criteria for exemption are not met.

Beyond federal controls, sturgeon culture in general, and its environmental impact in particular are also managed under a range of state statutes, policies, and regulations.

In Idaho, applicable federal controls are supplemented by a state control system in which commercial fish farms are regulated through Titles 22 and 36 of the Idaho Code, with Title 22 administered by the Idaho State Department of Agriculture (ISDA) and Title 36 by the Idaho Department of Fish and Game. Key provisions require that all commercial aquaculture facilities are licensed by ISDA, with licenses renewed every other year and renewals subject to ISDA field staff inspection. Approval of each aquaculture operation's effluent control facilities by the Idaho Department of Environmental Quality (DEQ) is another licensing condition, since DEQ is responsible for protecting surface and ground water quality in Idaho and thereby – for ensuring and certifying that effluent discharges comply with the Clean Water Act and do not cause an exceedance of state water quality standards. Idaho DEQ also performs NPDES inspections of aquaculture facilities under contract with EPA. The disposal of dead fish from aquaculture facilities is regulated by the Idaho Department of Agriculture. Further, Idaho aquaculture facilities need water right permits from the Idaho Department of Water Resources.[12]

In California, state agencies with regulatory responsibilities over aquaculture include the California Department of Fish and Game, the California Department of Food and Agriculture, the State Lands Commission, the Coastal Commission, and the State Water Resources Control Board. The California Department of Fish and Game (CDFG) has been established as the lead agency for state aquaculture under the 1979 California Aquaculture Development Act. Among other things, CDFG therefore has the responsibility to promote cooperation and communication between aquaculture interests and the various state agencies that impact the industry.[13] Key state aquaculture regulations are covered in Title 12 of the California Fish and Game Code. These include requirements for CDFG registration and approval of all aquaculture facilities, with registration and approval subject to a review by regional biologists of the facility location, facility design, and species to be cultured. Under the California Fish & Game Code, CDFG is also responsible for permitting the importation of any live aquatic animals and plants, and, as discussed in previous sections, for permitting the collection and use of any wild broodstock. The Code also authorizes CDFG to prohibit an aquaculture operation or the culturing of any species at any location where it is determined it would be detrimental to adjacent native wildlife (Sec. 15102, Calif. F&G Code).

In Florida, the Department of Agriculture and Consumer Services (DACS), Division of Aquaculture, has regulatory authority over all aquaculture facilities in the state. This DACS authority stems from the Florida Aquaculture Policy Act of 1984, which also specifically directed the Department to develop a set of Best Management Practices for aquaculture and ensure that state aquaculture facilities are operated in compliance with these BMPs. Under the

---

[12] The Idaho Department of Environmental Quality and Idaho State Department of Agriculture websites can be consulted for more details:
http://www.deq.idaho.gov/water/prog_issues/agriculture/aquaculture.cfm#regulates
http://www.agri.state.id.us/Categories/Animals/fishFarms/indexfishmain.php

[13] See http://aqua.ucdavis.edu/government/cdfgnf.html for more details.

Florida BMPs, each aquaculture facility must be inspected and certified by DACS. Aquaculture certificates are issued annually and they list the aquatic species (usually to family or genus level) that the facility may culture. There are general aquaculture BMPs as well as BMPs specific to sturgeon.

The Florida BMPs cover numerous aspects of aquaculture operations, including the construction and operation of different types of aquaculture facilities, the use of fresh and saltwater resources, health management for cultured species, the use of drugs and therapeutants, the use and containment of non-native species, and the handling and disposal of mortalities (Florida Department of Aquaculture and Consumer Services, 2005). A certified producer must comply with all appropriate BMPs. The BMPs specifically incorporate practices for biosecurity and prevention of escape and are considered consistent with other Florida statutes and the rules of the Florida Fish and Wildlife Conservation Commission (FWC), which is the other state agency (in addition to DACS) with responsibility for regulating the use of non-native species in aquaculture, and the agency with primary legal responsibility for regulating and managing Florida's fish and wildlife resources (Hill, 2006).

Certified Florida aquaculture facilities are subject to unannounced BMP compliance visits by DACS staff, and sturgeon culture facilities have been subject to frequent such visits (Dr. Frank Chapman, Personal Communication).

Predation in sturgeon culture is generally controlled by the placement of anti-predator nets on outdoor tanks containing juvenile sturgeon. Predator control is not considered necessary for adult sturgeon due to their size.

**Synthesis**

Examination of the available data on regulatory provisions applicable to U.S. sturgeon culture suggests the presence of a relatively comprehensive system of regulatory controls and points to an adequate application of these controls in the management of environmental and other aspects of sturgeon culture. Analysis of the available data also suggests general consistency in coverage and implementation among the management regimes specific to each of the three states in which sturgeon is currently cultured. The management of sturgeon culture can therefore be considered effective at the present time.

**Management effectiveness rank:**

[✓ Effective 🟩] Moderately effective 🟨 Ineffective 🟥

## Overall evaluation

U.S. farmed sturgeon and caviar rank as a "Good Alternative," when the over-all sustainability of their production is evaluated according to the following five Seafood Watch® criteria: 1) Use of marine resources, 2) Risk of escapes to wild stocks, 3) Risks of disease and parasite transfer to wild stocks, 4) Risk of pollution and habitat effects, and 5) Effectiveness of the management regime. One of the factors most significant in contributing to this ranking is the extensive use of marine resources, in the form of feed, which is still characteristic of sturgeon culture. Although the amount of fishmeal and fish oil used in sturgeon feed, as well as the feed conversion ratios of cultured sturgeon may decrease in the future, their current levels warranted a red, "high use of marine resources" ranking at the present time. Further, given the nature of current sturgeon culture facilities and practice and the types of disease agents and disease transmission mechanisms known for sturgeon, there is some concern that disease outbreaks in farmed populations may affect wild fish populations, although there is presently no evidence that such effects have actually occurred. The concern is essentially due to the releases of wastewater which may contain disease-causing organisms. The risks of disease transfer from farmed to wild sturgeon have consequently been ranked as yellow, or "Moderate." U.S. sturgeon culture ranks green on the three remaining criteria. It is important to point out that although the ecological consequences of farmed fish escapes, especially the escapes of non-native sturgeon, can be serious, the biosecurity practices used by culture facilities and the reported absence of escapes has prompted the assignment of "Low" escape risks not only to those California and Idaho facilities that are exclusively culturing native sturgeon strains but to Florida facilities that exclusively focus on the rearing of non-native sturgeon. Finally, both effluent management and the over-all management regime for sturgeon culture have, on the basis of available data and evidence, been assessed as highly effective, prompting a green "low risk" ranking in these two categories.

## Table of Sustainability Ranks

| Sustainability criteria | Conservation Concern | | | |
|---|---|---|---|---|
| | **Low** | **Moderate** | **High** | **Critical** |
| Use of marine resources | | | √ | |
| Risk of escapes to wild stocks | √ | | | |
| Risk of disease and parasite transfer to wild stocks | | √ | | |
| Risk of pollution and habitat effects | √ | | | |
| Effectiveness of management | √ | | | |

## Overall Seafood Recommendation for U.S. Farmed Sturgeon and Caviar

Given the favorable rankings of U.S. sturgeon culture under the majority of our sustainability criteria, the fact that U.S. sturgeon culture is poised for further improvements in the over-all sustainability of production, and also the fact that the majority of wild-caught sturgeon species and their products will remain on the Seafood Watch "Avoid" list for a variety of reasons (many of which are elaborated in the separate Seafood Watch wild sturgeon report), we recommend U.S. farmed sturgeon and caviar as a good seafood alternative.

Best Choices 🟩 [✓ Good Alternatives 🟨] Avoid 🟥

## Acknowledgements

The author would like to thank Dr. Serge Doroshov and Dr. Joel Van Eenennaam from UC Davis, and Gary Fornshell from University of Idaho, who provided many insightful comments throughout the process of research and evaluation, and who reviewed an earlier draft of this report. I am also grateful to Dr. Ronald Hedrick at UC Davis, Dr. Terry Patterson at the College of Southern Idaho, and Dr. Frank Chapman at the University of Florida, Gainesville, for providing especially valuable data, insights, and literature suggestions. Finally and very importantly, I really appreciate the patience and insights of Peter Struffenegger at Sterling Caviar/Stolt Sea Farms and Dr. David Stephen at the Tsar Nicoulai Caviar sturgeon farm, both of whom took time throughout the course of this research and evaluation to discuss various aspects of their sturgeon culture operations with me; their input was especially valuable for building an understanding of current culture practices and operations.

## References

Adler, Carlye. October 12, 2006. High-grade caviar, low-grade price tag. Forbes Small Business Magazine. http://money.cnn.com/2006/10/05/magazines/fsb/caviar_tastetest.fsb/index.htm?postversion=2006100606 (Last retrieved January 27, 2007).

Arndt, G.-M., J. Gessner, and C. Raymakers. 2002. Trends in farming, trade and occurrence of native and exotic sturgeons in natural habitats in Central and Western Europe.. Journal of Applied Ichthyology, 18: 444–448.

Beveridge, M.C.M. 1996. Cage aquaculture (2nd edition). Edinburgh, Scotland: Fishing News Books, 346 pp.

BioMar. 2005. Biomar Sturgeon Feed and Sustainability. Information Sheet.

Binkowski, F. P., and S. I. Doroshov, eds. 1985. North American sturgeons : biology and aquaculture potential : papers from a symposium on the biology and management of sturgeon, held during the 113th Annual Meeting of the American Fisheries Society at Milwaukee, Wisconsin, U.S.A., August 16-20, 1983. Dordrecht/Boston.

Birstein, V., J. Waldman, and W. Bemis. 1997. Sturgeon Biodiversity and Conservation. Kluwer Academic Publishers, Dordrecht/Boston/London.

Blazer, V.S., and S.E. LaPatra. 2002. Pathogens of cultured fishes: potential risks to wild fish populations. Pages 197-224 *in* J. Tomasso, ed. Aquaculture and the Environment in the United States. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA.

Carlton, J. T. 1992. The dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. Pages 13-45 *in* A. Rosenfield and R. Mann, eds. Dispersal of living organisms into aquatic ecosystems. Maryland Sea Grant Publication, The University of Maryland, College Park, MD.
Carlton, J. 2001. Introduced species in U.S. coastal waters: Environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia.

Carr, J. and F. Whoriskey. 2004. Sea lice infestation rates on wild and escaped farmed Atlantic salmon (*Salmo salar* L.) entering the Magaguadavic River, New Brunswick. Aquaculture Research 35:723-729.

Chapin, L. 2006. A ban on imported roe could be a watershed event for U.S. company. The Kansas City Star, January 3, 2006.

Cliff, D. 2005. Sustainable sturgeon: Tsar Nicoulai's guilt free caviar. (http://www.ediblesacramento.com/pages/articles/winter2005/winter2005.htm - Last accessed Dec. 03, 2006).

Costa-Pierce, B.A. 1996. Environmental impacts of nutrients from aquaculture: Towards the evolution of sustainable aquaculture systems. Pages 81-113 *in* D.J. Baird, ed. Aquaculture and water resource management. Blackwell Science, Oxford.

Davis G. E., P. L. Haaker, and D. V. Richards. 1998. The perilous condition of white abalone *Haliotis sorenseni*, Bartsch, 1940. Journal of Shellfish Research, 17(3): 871–875.

Dettlaff, T.A., A.S. Ginsburg, and O.I. Schmalhausen. 1993. Sturgeon fishes : developmental biology and aquaculture. (Translated by G.G. Gause and S.G. Vassetzky). Springer-Verlag: Berlin, New York.

Doroshov, S. I., G. P. Moberg, and J. P. Van Eenennaam. 1997. Observations on the reproductive cycle of cultured white sturgeon, *Acipenser transmontanus.* Environmental Biology of Fishes, 48: 265-278.

Doroshov, S. I. 1985. Biology ad culture of sturgeons, Acipenseriformes. In Recent Advances in Aquaculture, Vol. 2. J. F. Muirs and R. J. Roberts, eds. Westview Press: Boulder, Colorado.

Drennan, J.D., S. Ireland, S. E. LaPatra, L. Grabowski, T. K. Carrothers, and K. D. Cain. 2005. High-density rearing of white sturgeon Acipenser transmontanus (Richardson) induces white sturgeon iridovirus disease among asymptomatic carriers. Aquaculture Research, 36: 824 – 827.

Farley, C. A. 1992. Mass mortalities and infectious lethal diseases in bivalve mollusks and associations with geographic transfers of populations, in Rosenfeld and Mann, Eds. Dispersal of Living Organisms into Aquatic Ecosystems. Maryland Sea Grant, College Park, Maryland. Pp. 139-154.

Florida Department of Agriculture and Consumer Services. 2005. Aquaculture Best Management Practices Manual. Division of Aquaculture, Tallahassee, FL. http://www.floridaaquaculture.com/Pub.htm

Georgiadis, M.P., R.P. Hedrick, T.E. Carpenter, and I.A. Gardner. 2001. Factors influencing transmission, onset and severity of outbreaks due to white sturgeon iridovirus in a commercial hatchery. Aquaculture, 194: 21 – 35.

Georgiadis, M. P., R. P. Hedrick, W. O. Johnson, S. Yun, and I. A. Gardner. 2000. Risk factors for outbreaks of disease attributable to white sturgeon iridovirus and white sturgeon herpesvirus-2 at a commercial sturgeon farm. American Journal of Veterinary Research, 61 (10): 1232-1240.

Hardy, R., G. Fornshell, and E. Brannon. 2000. Rainbow trout culture. Pages 716-722 *in* R. Stickney, ed., Encyclopedia of Aquaculture. John Wiley & Sons, New York.

Hedrick, Ronald. 1999. Letter to Dr. Marshal Jones, Assistant Director of International Affairs, US FWS. Pp. 151-152 *in* Metcalf and Zajicek, eds. Proceedings of the Florida Sturgeon Culture Risk Assessment Workshop, April 6-7, Sarasota, FL. Florida Department of Aquaculture and Consumer Services. 2001.

Hedrick, R.P., Groff, J.M., McDowell, T.S. and Wingheld, W.H., 1990. An iridovirus infection of the integument of the white sturgeon *Acipenser transmontanus*. Diseases of Aquatic Organisms, 8: 39-44.

Hill, J. E. 2006. Regulations Pertaining to Non-native Fish in Florida Aquaculture. Paper FA-121 in the series of the Fisheries and Aquatic Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. (http://edis.ifas.ufl.edu/FA121 - Last accessed on November 23, 2006).

Hinshaw, J. M., G. Fornshell, and R. Kinnunen. 2004. A profile of the aquaculture of trout in the United States.

IUCN Sturgeon Specialist Group. 2004. Sturgeon Conservation and The Red List: List of assessment of taxa from order Acipenseriformes (sturgeons and paddlefishes) included in the 2004 IUCN Red List of Threatened Species.
http://www.iucn.org/themes/ssc/sgs/sturgeon/redlist.html

Ivakhnenko, R. 2001. A new method of sturgeon conservation in Russia. CITES World Newsletter, Issue 8, p. 13. Available online at http://www.cites.org/eng/news/world/8.pdf

Krkosek, M., M. Lewis, A. Morton, L. N. Frazer, and J. Volpe. 2006. Epizootics of wild fish induced by farm fish. PNAS, 103(42): 15506–15510.

Krkosek, M., M. Lewis, and J. Volpe. 2005. Transmission dynamics of parasitic sea lice from farm to wild salmon. Proceedings of the Royal Society of London, Series B 272:689-696.

Kuris A. M. and C. S. Culver. 1999. An introduced sabellid polychaete pest of cultured abalone and its potential spread to other California gastropods. Invertebrate Biology, 118(4): 391–403.

Kwak, K. T., , I. A. Gardner, T. B. Farver, and R. P. Hedrick. 2006. Rapid detection of white sturgeon iridovirus (WSIV) using a polymerase chain reaction (PCR) assay. Aquaculture, 254: 91-101.

LaPatra, S.E., J.M. Groff, G.R. Jonesa, B. Munnc, T.L. Pattersond, R.A. Halt, A.K. Hauckf, and R.P. Hedrick. 1994. Occurrence of white sturgeon iridovirus infections among cultured white sturgeon in the Pacific Northwest. Aquaculture 126: 201-210.

LeBreton, G. T. O., F. W. H. Beamish, and R. S. McKinley, eds. 2004. Sturgeons and Paddlefish of North America. Kluwer Academic Publishers: Dordrecht/Boston.

Lightner, D. V. et al. 1992. Dispersion of the viruses IHHN, MBV, and HPV as a consequence of transfers and introductions of penaeid shrimp to new regions, pp. 155-174 in Rosenfeld and Mann, eds. Dispersal of Living Organisms into Aquatic Ecosystems. Maryland Sea Grant, College Park, Maryland.

McDougal, P. 2005. Commercially wild-caught sturgeons and paddlefish. Seafood Watch Seafood Report. Monterey Bay Aquarium.

Metcalf, K. and P. Zajicek, eds. 2001. Proceedings of the Florida Sturgeon Culture Risk Assessment Workshop. Florida Department of Agriculture and Consumer Services, Division of Aquaculture.

Milstein, V. 1971. Centenary of sturgeon culture. Pp. 5-13 *in* Sturgeons of the USSR and Their Reproduction, Nauka Press, Moscow (in Russian).

Mims, S. D. 2001. Aquaculture of paddlefish in the United States. *Aquatic Living Resources*, 14: 391-398.

Mims, S. D. A. Lazur, W. L. Shelton, B. Gomelsky, and Frank Chapman. 2002. Species profile: Production of Sturgeon. Southern Regional Aquaculture Center, Publication No. 7200.

Naylor, R. and M. Burke. 2005. Aquaculture and Ocean Resources: Raising Tigers of the Sea. *Annual Review of Environment and Resources*, 30: 185-218.

Naylor, R.L, R.J. Goldburg, J. H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies. Nature 405:1017–1024.

Naylor, R. S**.** R. J. Goldburg, H. Mooney, M. Beveridge, J. Clay, C. Folke, N. Kautsky, J. Lubchenco, J. Primavera, and M. Williams. 1998. Nature's Subsidies to Shrimp and Salmon Farming. *Science,* 282 (5390): 883 – 884.

Naylor, R., S. Williams, and D. R. Strong. 2001. Aquaculture - A gateway for exotic species. Science 294:1655-1656.

O'Neill, B. 2006. U.S. farmed rainbow trout. Seafood Watch Seafood Report. Monterey Bay Aquarium.

Paone, S. 2000. Industrial Disease: The Risk of Disease Transfer from farmed Salmon to Wild Salmon. Friends of Clayoquot Sound, Tofino, BC, Canada. 16 pp.

Raloff, J. 2006. Caviar Caveats. Science News Online, Week of March 4, 2006. http://www.sciencenews.org/articles/20060304/food.asp (Last viewed Sept. 27, 2006)

Raymakers, C. 2002. International trade in sturgeon and paddlefish species – the effect of CITES listing. International Review of Hydrobiology, 87: 525-537.

Raymakers, C., and and C. Hoover. 2002. Acipenseriformes: CITES implementation from Range States to consumer countries. Journal of Applied Ichthyology, 18: 629-638.

Ronyai, A. and L. Varadi. 1995 The sturgeons. In Reproduction of Aquatic Animals: Fishes, pp 95–108. C. E. Nash and A. J. Novotny, eds. World Animal Sciences C8. Amsterdam, Elsevier.

Rosenfeld, A., and R. Mann. 1992. Dispersal of Living Organisms into Aquatic Ecosystems. Maryland Sea Grant, College Park, Maryland.

Rosenthal, H. R. M. Bruch, F. P. Binkowski, and S. I. Doroshov. 2002. Highlights of the 4th International Sturgeon Symposium: Session Summaries, Conclusions and Recommendations. Journal of Applied Ichthyology, 18: 221-225.

Salisbury, S. 2006. Florida farmers could see caviar dreams come true. The Palm Beach Post, Nov. 06, 2006. (https://registration.miami.com/reg/login.do?url=http%3A%2F%2Fwww.miami.com%3A80%2Fmld%2Fmiamiherald%2Fbusiness%2Fspecial_packages%2Fbusiness_monday%2F15927159.htm Last accessed Nov. 6, 2006)

Tetreault, I. 2006. Farmed Tilapia. Seafood Watch Seafood Report. Monterey Bay Aquarium.

Tyedmers, P. H. 2000. Salmon and sustainability: the biophysical cost of producing salmon through commercial salmon fishery and the intensive salmon culture industry. Doctoral Dissertation, The University of British Columbia. 272 pp.

USDA, 2006. Census of Aquaculture (2005). Volume 3, Special Studies, Part 2, AC-02-SP-2.

Van Eenenaam, J. P., F. Chapman, and P. Jarvis. 2004. Aquaculture. Pp. 277-311 *in* Le Breton et al., eds. Sturgeons and Paddlefish of North America. Kluwer Academic Publishers, Dordrecht/Boston/London.

Van Winkle et al. 2002. Biology, Management, and Protection of North American Sturgeon. American Fisheries Society Symposium 28. American Fisheries Society, Bethesda, Maryland.

Wei, Q., J. He, D. Yang, W. Zheng, and L. Li. 2004. Status of sturgeon aquaculture and sturgeon trade in China: a review based on two recent nationwide surveys. Journal of Applied Ichthyology, 20: 321-332.

Williamson, D. F. 2003. Caviar and Conservation: Status, Management and Trade of North American Sturgeon and Paddlefish. TRAFFIC North America. Washington, DC. May 2003. 252 pp.

Williot, P. et al. 2005. Cultured Aquatic Species Information Programme - Acipenser baerii. *Cultured Aquatic Species Fact Sheets*. FAO Inland Water Resources and Aquaculture Service (FIRI). http://www.fao.org/figis/servlet/static?dom=culturespecies&xml=Acipenser_baerii.xml [Accessed Oct 16 2006].

Williot, P., L. Sabeaub, J. Gessnerc, G. Arlatid, P. Bronzie, T. Gulyasf, and P. Berni. 2001. Sturgeon farming in Western Europe: recent developments and perspectives. Aquatic Living Resources, 14: 367-374.

**Personal Communications**

Dr. Frank Chapman, Associate Professor, Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville.

Dr. Serge Doroshov, Professor, Department of Animal Science, University of California, Davis.

Gary Fornshell, Aquaculture Extension Specialist, Twin Falls County Extension, University of Idaho.

Dr. Ronald Hedrick, Professor, Department of Medicine and Epidemiology, University of California, Davis.

Dr. Terry Patterson, Professor and Manager, Aquaculture Program, Department of Agriculture, College of Southern Idaho.

Julia Roberson, SeaWeb, Coordinator for European Programs.

Dr. David Stephen, Chief Production Scientist, Tsar Nicoulai Sturgeon Farm, Wilton, California.

Peter Struffenegger, General Production Manager, Sterling Caviar LLC, Stolt Sea Farms, Sacramento, California

Dr. Joel Van Eenennaam, Staff Research Associate, Department of Animal Science, University of California, Davis.