Diagnostic information

*Aurelia aurita*, is of the Phylum Cnidaria, which are characterized by having a polyp and medusa stage, radial symmetry, planula larvae, cnidia, and tentacles around the mouth. Classified under the Class of Scyphozoa qualifies the species as a “true jelly,” that is primarily found in medusoid morphology, with asexual reproduction in the polyp stage via strobilation (Dawson and Martin, 2001). It is also of the Order Semaeostomae, Family Ulmaridae, Genus Aurelia, and species *Aurelia aurita*. The particular species *Aurelia aurita* is often called “moon jelly,” after its milky, translucent color and shape. The term “jellyfish” also refers to its gelatinous body (Richardson et al, 2009). However, *A. aurita* is obviously not made of jelly nor a fish species, but instead a free-flowing creature that is able to propel itself though the water with muscular contraction of it’s bell, but is not able move against currents, which technically makes it a planktonic species. While there are approximately 12 *Aurelia* subspecies that have been described, *A. aurita* is one of two that has been classified as its own distinct species (Russel 1970). Current studies are using molecular evidence to identify the organism through genotypic and mitochondria DNA sequencing (Ki et al., 2008). Identification is further complicated due to the high variation in phenotypic expression of the different life stages. The 5-7 horseshoe shaped rings are the digestive stomach pouches. The gonads lie just below, and are readily visible in females as pink and purple clumps. Tiny tentacles surround the bell shaped dome. Prey becomes stunned by the nematocysts (stinging cells) in the tentacles and are then moved via cilia to the mouth which is located on the underside of the organism. Contractions of the bell pulse and propel the animal through the water column. However, they are unable to overcome current forces, which technically classifies the organism as plankton.

**FAO**

Fig. 1. Drawn illustration of *Aurelia aurita* (http://www.sealifebase.org/Photos/PicturesSummary.php?StartRow=4&ID=44404&what=species&TotRec=6)

2 Moon Jelly (*Aurelia aurita*) ([www.jellieszone.com](http://www.jellieszone.com))
Life History and Basic Ecology

*A. aurita* is in the class *Scyphozoa*, which means that it will eventually undergo asexual reproduction via strobilation while in the polyp morph, and sexually reproduce as a medusa morph. In the Pacific Northwest and other temperate regions, the jellyfish asexually strobilates as a polyp during the spring, is able to rapidly grow during the summer, and reproduces sexually as a medusa in the fall before senescing between autumn and winter (Dawson and Martin 2001). The species does show some seasonal changes in bell diameter size (Lucas, 2001). Typically medusae are small in size during winter to early spring, which is a result of nutrient and light limitations. Once zooplankton and phytoplankton blooms occur in the spring, growth in bell diameter increases exponentially.

In most cases, the individuals shrink again when preparing to sexually reproduce and release gametes. It remains difficult to age a specimen, since size averages differ regionally. Typically, medusae life spans range from 4-8 months and do no exceed 1 year, though a few exceptions do occur. Age studies have determined that the number of branching points in the radial canals of the water vascular system increase with time, allowing scientist to use this change in physiology to age an individual. While selection occurs at every stage of the life cycle, at any given habitat, distribution and abundance is dependent on recruitment via sexual reproduction, migration, mortality, and asexual reproduction. Mortality has highest impact upon population abundance at the polyp stage.

In the Adriatic Sea, *A. aurita* has been observed showing diel migrations in pursuit of zooplankton and microbial bacteria (Malej et al., 2008). At night, the jellyfish could typically be found deeper in the water column, from 24m to 32m. During the day, *A. aurita* typically gathered in the thermocline, which was around a depth of 20m. The experiment focused on individuals with a bell diameter of 4.9-11.4 cm, and they typically found 27 prey items per medusa. Gut contents of *A. aurita* contained larvae of *Gastropoda*, *Bivalva*, *Cirripedia*, *nauplii*, and *Appendicularia*, but were primary composed of copepods. While they didn’t appear to be eating at night, the authors of the paper believe migration occurs due to metabolic advantage and tidal distribution avoidance.

Fig. 3 Shows the life cycle and reproduction cycle of *Aurelia aurita* (Muller and Leitz, 2002)
Other studies have shown that *A. aurita* may be capable of absorbing dissolved organic matter (Shick, 1973) and even capable of sorting its food to maximize fulfilling its nutritional needs (Dawson and Martin 2001). In some cases, it has also been observed to degrow in times of starvation until sufficient nutrients become available.

To catch prey, *A. aurita* uses its cnidea and nematocysts, which are stinging cells found in the tentacles around its mouth to stun and poison their prey (Richardson et al., 2009). Food particles are then moved via cilia to the mouth where they then enter the digestive tract. Nutrients are then absorbed and stored in the digestive tract rings that are easily observed in the bell of the organism.

The species *A. aurita* reproduces sexually and asexually depending on what life stage it is in (Richardson et al., 2009). Medusae, which are the commonly known bell shaped forms of the species, are present generally in the spring through fall. They reproduce sexually before senescing. The haloplanktonic larvae then develop into polyps, and through the strobilation process, reproduce asexually from winter through the spring. Large blooms of medusae during the summer ensure that planulae larvae are fertilized before settling and metamorphosing into benthic polyps (Hamner and Dawson, 2009). Strobilation is the process of increasing body segmentation in benthic polyps of *A. aurita*. Once, they are through with this process, asexually budding of the benthic strobila produces ephyrae, which are essentially small jellyfish (Liu et al., 2008). This process occurs through late winter to early spring. These ephyrae then develop into the medusa form of the species. Studies conducted showed that there was a negative correlation between increased temperature and light intensities and budding rates. While strobilation proceeded at faster rates, it appears that excess budding rates that create larger blooms can occur more frequently in temperate regions in comparison to tropical regions. Timing of this process varies globally depending on temperature, nutrients, and light intensity (as depicted in Fig. 4).

![Fig. 4 Timing of the appearance of ephyrae, medusae, and planula-bearing medusae in a variety of Aurelia aurita populations globally (Lucas, 2001)](image-url)
There appears to have been a worldwide expansion of *A. aurita* populations, though it is difficult to truly know if the species was native or introduced due to lack of data. However, spread and establishment is easily achievable due to the species wide tolerance of environmental conditions from temperate to tropical regions. (Malej et al., 2007). Studies have shown that the jellyfish prefer positioning themselves near the bottom of the thermocline layers in areas with low salinity and temperatures lower than 19 °C. However, as aforementioned, the jellyfish are quite abundant in the tropics. This generalist capacity allows them to successfully spread and establish in a great range of regions. There also seems to be a correlation between environment characteristics and *A. aurita* population size (Dawson and Martin, 2001). Surveys have found that large bloom of medusa in temperate regions are generally found in fully or semi-closed environments, which may be behind key factors of survival such as “reduced advection, dilution and predation compared to more habitats” (266, Dawson and Martin, 2001). Therefore it is reasonable to assume that environmental conditions may decide how large an *A. aurita* invasion may be. Such blooms are not typically seen in the tropics, though the species goes through several life cycles a year. Global warming and rising ocean water temperatures are likely to facilitate future blooms. Also, smaller jellyfish blooms tend to have individuals with large bell diameters relative to and enclosed system. This may reflect the organism’s lack of intraspecies competition for available nutrient resources. Temperature too may be a component influencing the organism’s growth rate and metabolic processes. There are also seasonal growth patterns displayed by *A. aurita* (Lucas, 2001). Typically, medusae growth is slow from winter until early spring, due to temperature and nutrient limitations. High nutrient concentrations and increased temperatures in the water column allow the individuals to grow exponentially, until autumn causes the animals to shrink in size with the

![Fig. 5 Multiple-population relationship between maximum diameter and medusa abundance of Aurelia aurita (Lucas, 2001).](image-url)
process of gamete release. A high tolerance for low dissolved oxygen content also allows the jellyfish to prey upon copepods that become more susceptible to predation in such conditions (Richardson et al., 2009). Furthermore, such tolerance allows it to out-compete predators and competitors alike during hypoxic conditions. Presently, increased eutrophication events may encourage the invasive success of this creature. *Aurelia aurita* has been associated with the parasitic *Hyperia galba* in the Mediterranean Sea, which causes reduction in bell diameter, and occasionally the reduction in entire population size (Mills, 1993). Higher mortality rates were documented in times of limited nutrients when compared to periods of high nutrient content in the water column because less energy could be expended on wound healing and regeneration.

Pandalid shrimp also appear to have some sort of interesting relationship with the jellyfish species as well. On individuals with bell diameter large enough to withstand the size and weight of the shrimp larvae have been seen carrying the shrimp species while they pulse through the water column in the Northeast Pacific (Marliave and Mills, 1993). While the shrimp larvae do not directly harm the jellyfish, most of them die which may be attributed to the increased energetic expenditure. While there have not been any studies finding *A. aurita* with other organisms in a commensal relationship, there has been reports of planulae larvae settling on substrate in response to cues found in the environment of settled polyps (Muller and Leitz, 2002). It is believed that an unknown type of bacteria film releases cues into the water column that signal for suitable substrate to the free-flowing larvae. While sensory organs are limited, the larvae are equipped with mechanosensitive and chemosensitive neuron-sensory celled fitted with sensory cilium. The larvae then use these receptors to cue in on appropriate stimuli found in the water column. Authors of the study also believe the planula larvae are able to use air bubbles released by suitable sediment that cause them to settle and begin metamorphosis.

**Current Geographic Distribution**

This figure below is a map from the United States.
States Geological Survey website that displays *A. aurita*'s native range and invasion sites. Believed to be native to the Atlantic Ocean, the jellyfish has been introduced to the Pacific Ocean, and other regions globally primarily through transportation via ship ballast water and hull fouling.

**History of Invasiveness**

According to reports, *A. aurita* was first described and documented in the high productive waters of the Mid Atlantic near the Mississippi River delta (Mills, 2001). During the 1980’s, massive *A. aurita* blooms were documented in the native region as well as outside of this range. In the Pacific, the species has existed in Japan since 1891, with sightings in Tokyo dating back to 1915. It was not until the last 50 years did this species of jellyfish begin to become a nuisance, causing both economic and ecological damage in the Pacific. Survey reports show an unprecedented history of *A. aurita* blooms in the Bering Sea from 1980’s to 1990’s (Brodeur, Sugisaki, Hunt, 2002). Much of Alaska’s economic resources come from the fisheries, with seasonally high boat traffic that travels along the West coast of the United States. While it still remains largely unclear where exactly the jellyfish originated from, it is highly likely that ballast water and hull fouling contributed to the growing problems arising from the emergent population. Regions of known populations believed to be native are also experiencing unprecedented increases in *A. aurita* populations (Graham, 2001). Increased nutrient discharge, increased fishery programs, and change in predatory species populations in the Gulf of Mexico are all factors believed to be contributing the change in jellyfish presence.

**Invasion Process**

This species has been able to rapidly expand its range through both natural and anthropogenic means (Dawson et al., 2005). Anthropogenic transportation vectors of polyps include ship hulls, ballast water, aquarium trade and aquaculture (Grosholz, 2002). Marine organisms that exhibit high dispersal potential generally have little genetic structuring the in the population since gene flow is over great distances (Faleh et al., 2009). Since *A. aurita* planktonic larvae can last up to 30 days, and travel just large distances anywhere from 38-45 km, it is able to survive transoceanic transportation (Ki et al., 2008). Using genetic homogeneity measurements, researchers were able to assess how similar *A. aurita* species are at different regions worldwide (Dawson and Martin, 2001). The results showed that invasive species populations in eastern part of the Pacific Ocean and Japan were genetically similar to the native populations in Southern California. Therefore, the jellyfish populations that have become established in the Pacific Northwest most likely originated from California predominately though ballast water and ship
hulls. Where and how the original population came to be transported to California is undocumented, but most likely from ships. Many scientists maintain that disturbed environments are more susceptible to invasion. In the case of *A. aurita*, over fishing of native pelagic fish has made establishment and success rates much higher (Richardson et al., 2009). Many of these removed fish species compete with the jellyfish for zooplankton, and often prey upon the polyps, ephyrae, and small medusae. Removing one of the few predators jellyfish have, such as fish, turtles, and birds, *A. aurita* is able to reproduce and gather nutrients uninhibited. Also, trawling is typically done in softer substrate so as to avoid tearing the nets. However, polyps generally seek refuge in rockier areas that are not commonly trawled. This means that more polyps are able to survive and bud off ephyrae that morph into medusae blooms. These trawls also remove jellyfish predators from the food web. Other research points to eutrophication that influences establishment and success of the jellyfish. Excess nutrient run off encourages phytoplankton blooms. This shift in plankton size from large to small means that larger species higher up in the food web are inefficiently consuming a less nutritious diet causing declines in predator populations. Anthropogenic habitat may also be responsible for success in *A. aurita*’s invasion (Richardson et al., 2009). Mariculture, manmade pilings and platforms, and other hard substrate that is placed into the water, gives polyps a suitable substrate to attach to. Similarly, these manmade pilings and platforms generally support aquaculture (Lo et al., 2008). These areas become especially susceptible to invasion success because they are well supplied with nutrients and shade, which aid in polyp strobilation and budding. The young fish and shellfish themselves that are being raised in these facilities are also contributing to providing nutrients to the jellyfish, which result in economic loss. Furthermore, *A. aurita* becomes difficult to remove without substantially damaging the

Fig. 7 Fishing down marine food webs: the three stages (Pristine, Present, Future) offer increasingly better conditions for jellyfish (Pauly et al., 2009).
organism being raised for harvest. Chances are with the aquaculture industry’s prediction to increase in the future; jellyfish polyps will continue to take advantage of the suitable habitat.

The species’ physiology also aids in its establishment and success. This organism is a generalist with a broad diet, fast growth rate, which is able to survive in a wide range of oxygen, nutrient, light, and temperature conditions. These generalist traits allow the species to establish and spread in a variety of environments; often enabling them to out compete native species. Lack of predation in the novel habitat is another factor that contributes to the establishment and success of *A. aurita* (Hamner and Dawson 2009).

Recent blooms in Japan have cause economic damages for fisheries and power plants. Blooms tend to hinder trawl equipment on fishing vessels in addition to blocking seawater intake pipes of power plants (Grosholz 2002). The presence of large jellyfish blooms has also been detrimental to the tourist industry due to beach closings (Dawson and Martin, 2001). While stings from these species are generally mild, most people avoid visiting impacted areas or getting into the water. *A. aurita* has be described as a ruthless predator, and in areas of introduction, has been linked to eutrophication (Malej et al, 2008). Due to the overfishing of *A. aurita* predators, the jellyfish has been able to gorge on zooplankton and microbacteria unrestrained. The presence of *A. aurita* in some regions causes decreased copepod grazing pressure on phytoplankton, which may cause an increase in the primary production rates (Turk et al., 2008). This may indirectly cause other

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Fig. 8: Left *Aurelia aurita* jellyfish clog fishing nets in the Seto Inland Sea Japan. Right: *Nemopliema nomurai* jellyfish (maximum diameter 2 m; biomass up to 200 kg) collect in fish nets in coastal waters of Japan (Purcel, Uye, Lo, 2007)
ecological impacts including increased “red tides” or harmful algal blooms. While further studies need to be conducted, it appears that *A. aurita* may be causing regime shifts and trophic changes in its novel environment.

**Potential Management Strategies**

Since most introductions are caused and further facilitated by human activities, an appropriate management response will have to be comprehensive and widespread. One suggestion was to increase predation upon *A. aurita* (Richardson et al., 2009), for example Chinese culture has incorporated the jellyfish into their diet. Other short-term management policies include using cutting nets to destroy medusae, destructively cleaning substrates of polyps, and predator or disease bio-control introductions. Harvesting these species for food would decrease populations assuming the dish became popular, however it would be insufficient to cause large population declines or eradications. Similar short-term methods would also be costly in time and money, many without worthwhile gain. Suggestions for long-term strategies include increasing hull and ballast water cleaning protocols, restricting aquarium trade opportunities of live jellyfish, reduction in eutrophication, and over fishing (and/or restocking fish populations). These are all manageable vectors that if monitored appropriately could certainly reduce the number propagule pressure of invaded areas and introductions into new areas. However, most of these programs require multiple organization and government cooperation. Once policy makers are adequately educated on the problems of *A. aurita* invasion, hopefully they can promptly reorganize for safety of the economy and ecology of affected areas. However, often it is better to side with precaution; while eradication may not be plausible, preventing future introductions may be more lucrative.

**Expert in Pacific Northwest**

Claudia E. Mills is currently a profess in the Department of the Zoology at the University of Washington. Since 1978, she has been a resident researcher at the Friday Harbor Laboratories, specializing in gelatinous zooplankton fauna. While focusing on population and individual levels, she has recently begun to focus her work on the ecosystem level with increasing jellyfish blooms and their subsequent impact on the environment. Friday Harbor Laboratories and Department of Zoology, University of WA

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**Current Research and Management**

It appears that most *A. aurita* invasive populations appear to be introduced through
shipping practices, aquarium trade, and aquaculture. Current and future research is focusing on using molecular markers to trace the routes of introductions (Dawson and Martin, 2001). This would shed light on genetic contributions that factor in successful introductions, as well as allow policy makers to more effectively manage and monitor introduction routes that are especially vulnerable to transporting non-natives into new environments. Distinguishing phenotypic plasticity characteristics would also allow scientists to monitor genetic flow between natives and non-native species. Also, understanding and incorporating this species in marine ecosystem models will give scientists a better simulation that will predict a more realistic outcome, further increasing management competence.

Other current research is geared toward understanding medusa reproductive strategy in response to environmental conditions (Lucas, 2001), which would help predict future blooms and population outbreaks. Similarly, taking a more comprehensive look at how these jellyfish are interacting with their environment will give those studying and managing the situation more effective strategies.

Current fishery management will also indirectly manage and curb increasing *A. aurita* populations. As aforementioned, overfishing of the jellyfish’s natural predators has allowed the species to exploit new environments uncontrolled. By carefully maintaining healthy fish stocks, both the fish and jellyfish management will contribute to reducing the invasion problems. Present government and fish and wildlife programs that are currently underway will hopefully err on the side of precaution when evaluating and assessing current fish populations, which in turn will ensure that the jellyfish is not allowed to overtake and surpass current population sizes.

**Literature Cited**


Mills, C. E., 1993. Natural Mortality in NE Pacific Coastal Hydromedusae- Grazing


Other Key Sources of Information and Bibliographies

Further identification and classification of Aurelia aurita and other marine invertebrates can be found at (http://www.mbl.edu/BiologicalBulletin/KEYS/INVERTS/3/Dscyphozoakeys.htm) by the Marine Biological Laboratory, Biological Discovery in Woods Hole. Using a dichotomous key can aid in identifying organisms based on unique characteristics.

SeaLifeBase (www.sealifebase.org) is an online database of marine organisms that can be classified by taxonomy, life history traits, and geographic distribution.

Ecopath with Ecosim (www.ecopath.org) is an online database of ecological/ecosystem modeling software which can be used to “address ecological questions, evaluate ecosystem effects of fishing, explore management policy options, analyze impact and
placement of marine protected areas, predict movement and accumulation of contaminants and tracers, and model effect of environmental changes.

USGS Non-Indigenous Aquatic Species database (www.nas.er.usgs.gov) is an online database monitoring the geographic distribution of non-native and invasive species, along with vectors of introduction and population size.

Claudia Mills, one of the leading experts in jellyfish blooms and ecosystem contributions in the Pacific Northwest has a website that has many links to current research, published papers, and future projects regarding Cnidarians worldwide. (http://faculty.washington.edu/cemills/)

The Jellyzone (http://jellieszone.com/) is an online website dedicated to information on jellyfish and gelatinous zooplankton. Links include classification, information, recent news, and literature on the subjects. (http://jellieszone.com/aurelia.htm)
**Dichotomous Keys to Scyphozoa of the Woods Hole Region**

1. Planktonic Scyphozoa; medusoid in form; velum lacking
   - Benthic Scyphozoa; medusoid or polypoid in form
   - Tentacles on subumbrella, in eight U-shaped groups
   - Tentacles restricted to umbrella margin

2. 
   - Umbrella flat, plate-shaped; tentacles short, numerous; gonads four, horseshoe-shaped
   - Umbrella saucer-shaped to hemispherical; tentacles long

3. 
   - Umbrella lacking prominent warts, flatter than a hemisphere; margin with eight groups of 3-5 tentacles
   - Umbrella with prominent warts, hemispherical; margin with eight solitary tentacles

4. 
   - Body medusoid but attached; distal end with eight arms; tentacles usually present on each arm (STAUROMEDUSAE)
   - Body polypoid, small (1-3 mm); tenatacles in a single, distal whorl

5. 
   - Adhesive organs (anchors) present between arms; anchors kidney-shaped; gonads extending into arms (Fig. 1)
   - Adhesive organs (anchors) lacking; arms short; peduncle short

(http://www.mbl.edu/BiologicalBulletin(KEYS/INVERTS/3/Dscyphozoakeys.htm)

Fig. 9 Personal picture of stranded *Aurelia aurita* taken from the Southern Coast of Washington, July 2009.