Blackfordia virginica: The Black Sea Jellyfish

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Fig. 1. *Blackfordia virginica* taken from the Guadiana estuary on the boarder of Spain and Portugal.

Classification

Order: Lepthothecata
Family: Blackfordiidae
Genus: *Blackfordia*
Species: *virginica*

Identification Key

Blackfordia virginica, also known as the Black Sea jellyfish, is a relatively small translucent hydrozoan believed to be native to the Black Sea.

In its medusa stage, it typically has a bell width of approximately 14mm, with linear gonads extending into the radial canal from the bell margin and approximately 80 small tentacles with typically a single statocyte between each tentacle (Fig. 1). Its bell is typically wide, with a depth about half the width. The radial-canal/gonads are most commonly arranged in an 'X' pattern across the bell, although different morphologies have been observed (Fig. 2). Gonads and bell tips can have a slight yellow color to them, and the stomach can be slightly green.

In is polyp stage, it is extremely small (measured at typically 0.5 mm), with gonophores of similar size (Fig. 3). Both the polyps and gonophores are connected to one another through stolons (Mills and Rees 2000) Polyps possess small, webbed tentacles.

In all areas where *B. virginica* has be observed, both male and female individuals have been noted (Genzano 2006, Mills and Sommer 1995).

Life History and Ecology

Reproduction

Blackfordia virginica shares the complex reproductive cycle common to most hydromedusae. Sexually mature adults release eggs and sperm daily in to the water column. After fertilization and a period of growth, the eggs hatch, then settle on the bottom as planular

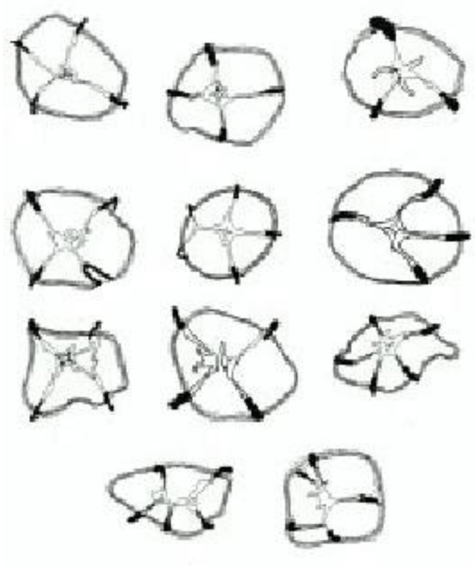

Fig. 2. Various radial-canal/gonad arrangements and morphologies of *Blackfordia virginica.* (Diagram taken from Silva *et al* 2003).

larvae. The planular larvae then form small (0.5 mm) benthic polyps, which reproduce asexually by budding to achieve a stacked colony of same-sex medusae. When conditions are favorable for the medusae (typically in the spring when plankton begin to bloom), they are released into the water column.

These newly released medusae are small at approximately 1 mm in diameter, but will eventually grow to their 14 mm adult length and reach sexual maturity.

Feeding Habits

Due to their small size, the diet of *Blackfordia virginica* tends to consist of small, planktonic organisms. Typically, this means small crustaceans: mostly barnacle nauplii and copepods and their eggs (Mills and Sommer, 1995). However, they are largely indiscriminate predators, and have been shown to eat a wide variety of things, including other invertebrates and fish larvae and eggs (Wintzer *et al* 2013, Chicharo *et al* 2009), which has been shown to aid in their ability to become invasive in new habitats (Richardson *et al* 2009)

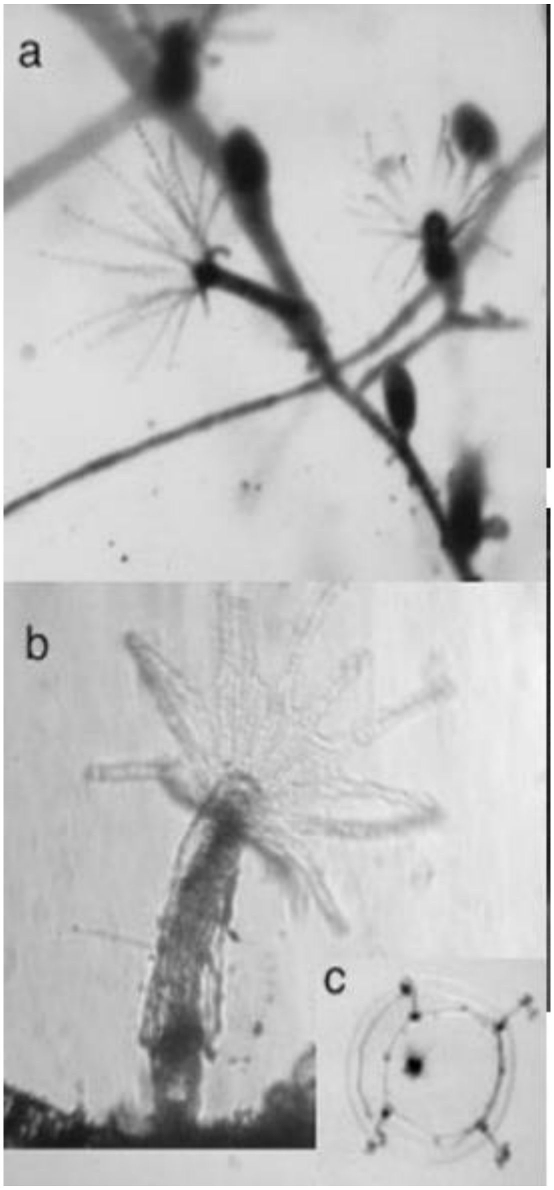

Fig. 3. The various life stages of *B.virginica.* (A) Polyp connected through stolons. (B) A single polyp. (C) The medusa stage. Figure from Mills and Rees (2000).

Environmental Conditions

There are a wide range of environmental conditions *Blackfordia virginica* is able to tolerate. It is most commonly found in estuarine environments, and has been shown to be tolerate salinities of 3-35 ppt (Moore 1987), temperature ranges of 16.5-23 °C, and dissolved oxygen ranges of 3.8-6.9mg/L (Wintzer *et al* 2013). Despite being able to tolerate these wide ranges, it seems to do best in warm, brackish water with high dissolved oxygen. However, biomass has been shown to be negatively correlated with increased current velocities.

Likely due to colder waters, increased mixing, and less phytoplankton, *B. virginica* populations tend to decrease to relatively low levels in the fall and winter, and then bloom in the spring, peaking in June (Wintzer *et al* 2013).

At their summer peak, their highest recorded density was 420 medusae/m^3 in the Bombay Harbor-Thana and Bassein Creek estuarine complex in India (Santhakumari *et al* 1997).

Distribution

The native range of *Blackfordia virginica* is widely believed to be the Black Sea, although this is somewhat debated, since the organism is so wide spread. Research into genetic variability of US populations makes it seem likely that the organism did not originate in the United States as has been previously theorized, because US populations do not have the genetic variability expected of a long-established population (Harrison *et al* 2014). While genetic samples have not been taken from the population of *Blackfordia virginica* in the Black Sea to confirm it is the origin of the species, it is widely believed to be so due to mapping of the species' distribution though time (Mills and Sommer 1995).

Whatever the original native range of *Blackfordia virginica*, it now can be found in estuarine environments in at least 13 countries throughout the world: Argentina, Brazil, Bulgaria, China, France, India, Cuba, Canada, Mexico, Guatemala, Jamaica, Mexico, Portugal, Russia, South Africa, Spain, Ukraine, and the United States. In the United States, it can be found in New York, South Carolina, Virginia, New Jersey, Delaware, Louisiana, California, Maryland, Oregon and Washington.

Currently, there are only a few records of *B.virginica* in the Pacific Northwest, likely due to few instances of their observation. However, due to the fast and efficient nature of reproduction in *B.virginica* and the wide range of environmental conditions it is able to tolerate, even a single individual could easily give rise to the sort of invasion that occurred in the San Francisco bay estuary, where over 230 individuals were recorded per cubed meter.

Although both males and females of *B.virginica* have been recorded in all populations observed in scientific literature thus far, a related hydrozoan often found alongside *B.virginica* in invasions, *Maeotias marginata*, have been shown to have populations consisting only of one sex, suggesting that the entire population was derived from a single asexually reproducing polyp (Mills and Rees 2000). This kind of rapid invasion from a single individual could potentially occur with *B.virginica* populations as well, so even areas found to only have a single individual should be heavily monitored, to ensure that *B.virginica* does not spread further.

Invasion Process

Vector

The exact means by which *Blackfordia virginica* is introduced into non-native habitats is unknown, but it is widely believed to be associated with shipping, due to fact that most invaded areas are near shipping ports (Mills and Sommer 1995). Because of their small size, *B.virginica* could easily be transported by various shipping vectors without boat owners realizing its presence.

Out of potential shipping vectors, introduction through ballast water seems most likely, as either an adult or larval individual could easily be transported in such a way due to their small size. Indeed, ballast is recognized by most organizations and researchers as the most likely source of *B.virginica* (CSBO 1996), especially considering the long distances between many areas where *B.virginica* is established.

Besides the likely introduction by ballast, polyps could also colonize on the hulls of boats, and then release medusa into a non-native environment. This is the suspected route of introduction of *Maeotias marginata*, the hydrozoan similar to *B.virginica*, and thus should be considered a potential route for *B.virginica* as well. Where ballast could likely be a vector for long-distance introductions of medusas, fouling by polyps could be a shorter-distance vector for introduction.

Despite these conjectures, the unknown nature of their vector has made predicting both the actual native habitat and the invasion routes of *B.virginica* difficult, which potentially adds to its likelihood of spread.

Spread

Due to the wide variety of environments *B.virginica* can tolerate, its rapid reproductive strategies, and its flexible diet, it can be established and spread to new environments fairly easily.

Although they are primarily estuarine organisms, they have been shown to tolerate salinities of up to 35ppt, commonly known as the average salinity of seawater. This means, unlike many estuarine or freshwater invaders, they could potentially spread through ocean pathways to new estuarine environments, if the estuaries were relatively near each other (as they would be unlikely to survive in most ocean conditions for extended periods, due to stress from the high salinity). As previously mentioned, they also have wide tolerances for temperature and dissolved oxygen, meaning they have the potential to spread to a wide variety of reproduce both sexually and asexually at a fast rate and at variety of life stages, gives *B.virginica* a high potential to spread to new environments.

Fig.4. The invasive range of *Blackfordia virginica* in the United States. The legend in the bottom right corresponds to the number of records in the area- not abundance. Map taken from: http://nas2.er.usgs.gov/viewer/omap.aspx?SpeciesID=1050

These tolerances, along with their indiscriminate diet, small size, and ability to rapidly asexually and sexually reproduce, gives *B.virginica* a high potential to spread to new environments.

The high potential to spread to new environments has manifested itself in the growing documentation of *B.virginica* populations in a wide variety of habitats. Since its initial introduction to the Northeastern United States sometime before 1910, it has spread all along the East coast, covering a wide variety of temperature and salinity regimes. In the late 20th century, its spread to San Francisco Bay and subsequent bloom caused an increase in interest both in popular media and scientific literature (Mills and Sommer 1995). More recently, sightings of *Blackfordia virginica* have occurred in the Pacific Northwest, both in Oregon and Washington. This wide habitat distribution in the United States alone demonstrates *B.virginica's* high potential to spread to new locations, if given the appropriate vector. This high ability to spread is emphasized by the fact that, due to the low genetic varability amongst the populations of *B.virginica* in the United States, it is likely only a single introduction led to the current populations of *B.virginica* in the US (Harrison *et al* 2014).

Despite the potential for high levels of spread, likely due to their small size, it is often difficult to detect populations of *B.virginica* when they are not undergoing dramatic blooms and population increases. For example, sizeable populations of *B.virginica* were largely unnoticed in several Brazilian estuaries for at least 50 years (Freire 2014), allowing the species to spread unchecked. This level detection could also be occurring in other countries, meaning the spread of *B.virginica* could be much greater than is currently recorded.

Impacts

Although there have been no studies done on the conclusive impacts of *Blackfordia* *virginica* in a system, there have been many inferences of likely impacts based on how the ecological characteristics of *Blackfordia virginica* are known to cause impacts in environments.

Increased biomass of *B.virginica* medusa was shown to correlate with decreased densities of all species of local zooplankton (Chicharo 2009). Zooplankton are a vital food source for many organisms, and their consumption by a non-native (and largely inedible) invader such as *B.virginica* could have devastating effects on a local food chain. In estuaries, where *B.*virginica is most commonly found, this potential impact is profound, as often estuaries act as nurseries for juvenile fish (Blaber and Blaber 2006). These juvenile fish rely heavily on zooplankton populations as a food source, and competition with *B.virginica* for this resource could have heavy effects on fish populations as they can easily starve at this vulnerable life stage.

In addition to supplying food to higher trophic levels, zooplankton populations often contain larvae of economically and/or ecologically important species. The indiscriminate nature of *B.virginica*'s feeding habits could potentially decrease recruitment rates of these important species, which could either cause economic losses for humans directly, or cause a variety of ecosystem changes, depending on the types of species involved.

Indeed, past studies of similar invasive ctenophores have been shown to quickly consume up to 80% of the summer zooplankton population, which had damaging effects on many species within the ecosystem, including economically or ecologically important organisms that may prey upon the zooplankton, or whose prey is dependent upon the zooplankton (Chicharo 2006). These sort of effects could potentially occur with the introduction and spread of *B.virginica*, if their numbers were large enough.

In addition to food chain disruption, the presence of large medusa blooms can have various other detrimental effects on

Fig. 5. A bloom of comb jellies, demonstrating the potential density of gelatinous plankton blooms. Photo from: http://phys.org/news/2014-05-jellyfish-blooms-calm.html

environments (Fig. 5). If high densities are reached, their mass can obstruct light penetration through the ocean (Lo *et al* 2008), which can, naturally, be detrimental to photosynthetic organisms, or other organisms that rely heavily on light for survival.

Although the polyp stage does not have the potential for the large scale environmental impacts of the medusa stage, the polyp stage has been known to have impacts on sessile invertebrates. It has been observed covering the valves of barnacles; disrupting their feeding cycle, and could easily foul other sessile organisms such as mussels or oysters in a similar manner (Mills and Rees 2000). This fouling could have commercial implications if it hinders the feeding capabilities of commercially valuable shellfish, and ecosystem implications-such as disruption of food webs-if *B.virginica* lowers the fitness of the sessile organisms it colonizes.

There are often little benefits associated with an increase in non-native ctenophores, due to their lack of predators in many non-native enviromnents. However, *Blackfordia virginica* do have some predators which could benefit from their introduction, such as some species of nudibranchs (Mills and Sommer 2000).

Control and Management

Due to their small size, efficiency of spread, and relative lack of natural predators, there are no known realistic ways of complete eradication of *B.virginica* populations once established. Thus, as with all invasive species, prevention of introduction is the most effective way of controlling *B.virginica* populations. Since ballast water is their most likely vector for introduction, stricter regulations and more careful release of ballast water is important in preventing their introduction. This could include depositing of ballast water in fresh water outside of *B.virginica*'s salinity tolerance, UV filtration, or utilizing ballast-free ship designs. Cleaning and monitoring hulls for fouling by *B.virginica* polyps is also important to ensure it is not introduced to new environments.

In addition to controlling introduction, there are some measures which could decrease the likelihood of *B.virginica* becoming established. Since their diet depends on zooplankton, eutrophication could possibly lead to a higher chance of establishment. Controlling for eutrophication could decrease their populations. Similarly, dam blockage is known to be associated with increased invasive species, due mainly to the disturbance it causes in river habitats (Johnson *et al* 2008). It is likely that decreased blockage and increased flow from decreased river damming would make it more difficult for *B.virginica* to become established, both because of increased biotic resistance from healthy native populations, and decreased habitat suitability for *B.virginica* (i.e. increased flow rates and decreased salinity).

In some cases, the removal of fish has been linked to an increase in gelatinous zooplankton populations, such as those of *B. virginica*, possibly due to nutrient cycle disruption (i.e. more plankton present due to lack of predation by fish, or various other disruptions)(Parsons and Lalli 2002). Removal of fish could also lead to increased populations of *B.virginica*, particularly if the fish removed prey upon a shared food source of *B.virginica*. With those competitors remove, *B.virginica* would have an even greater chance of establishment. Thus, maintaining heathy fish stocks could be one step in ensuring *B.virginica* does not become established in new areas, and possibly could decrease their numbers in areas where they are already established.

Management Objectives and Current Research

In order to prevent future outbreaks of *B.virginica*, the prevention of introduction should be further emphasized in consideration to *Blackfordia virginica*. This could include closer monitoring of ballast water, or ensuring ballast is deposited in fresh water environments, where *B.virginica* is unable to survive (although this approach may not be entirely effective, due to the broad salinity tolerances of *B.virginica*).

Anti-fouling measures could be effective in ensuring *B.virginica* does not spread through polyp colonization, although this is likely not as important a vector as ballast.

More research is necessary to determine the exact means by which *B.virginica* is introduced into an environment. This could help aid in its future management, including establishing more specific policy to inhibit its introduction.

The specific impacts of *B.virginica* also must be further researched, in order to establish greater understanding of how future spread might affect ecosystems, and add appropriate urgency to its control.

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Other Key Sources

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USGS NAS: Blackfordia Virginica http://nas.er.usgs.gov//queries/FactSheet.aspx?speciesID=1050

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