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High Priority Invasive Species in Los Angeles County

Final Report

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Sustainable L.A. Grand Challenge

Course:

UCLA EE Biol 183

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Introduction

Human activities have interfered with the distribution ranges and dispersal barriers of many species for hundreds of years. Common methods of accidental dispersal include the use of contaminated equipment and the release of exotic pets (Hardion et al., 2014). The introduction of a species may also be deliberate, such as the relocation of species into a novel area for gardening, construction, erosion control, or food production (Hardion et al., 2014). Anthropogenically introduced species may threaten local ecosystem biodiversity by outcompeting native species for resources (Hardion et al., 2014). Therefore, the introduction of non-native species, which are key drivers of human-induced environmental change globally (Vitousek et al., 1997), alter the evolutionary trajectory of native species. This is accomplished by means of competitive exclusion, niche displacement, hybridization, predation, and ultimately, extinction (Shea, 2002). Species categorized as either threatened or endangered are particularly vulnerable to extinction (Wilcove et al., 1998). The resulting loss of native species constitutes an irreversible removal of evolutionary potential (Mooney et al., 2001), as well as a critical cause of ecosystem degradation.

The negative impact of invasive species on ecosystem health extend to a multitude of ecosystem goods such as agricultural products and fisheries. They also hinder ecological services that are typically provided by native species, such as clean drinking water and climate stabilization. This poses a threat because ecosystem goods and services are fundamental to human well-being (Daily et al., 1997). Translating this impact into a monetary value is often challenging. The lack of a concrete and precise economic impact assessment allow the burdens imposed by invasive species to be overlooked. This results in an “invisible tax” on ecosystem services that is rarely considered during decision making (Pejchar and Mooney, 2009).

Furthermore, invasive species have a direct impact on human and animal health (e.g., via toxins, thorns, and allergenic pollen). For example, mosquitoes, which are common vectors for disease, are capable of altering the transmission cycle of pathogens (Juliano and Lunibos, 2005). The introduction of new species of mosquitoes into novel areas has been facilitated by worldwide ship transport (Lunibos, 2002).

Given the broad and substantial burden of invasive species, urgency is required to control and limit their harmful impacts. Such a feat would necessitate specific knowledge regarding their biology, ecology, and geographic origin (Hardion et al., 2014). In the following review, we conducted a thorough assessment of five key invasive species in the County of Los Angeles, providing information on their origins, current distribution, ecological and health impacts, economic costs, as well as ideal management guidelines founded in scientific research.

Methods

Indicator species were selected for us by Elizabeth Reid-Wainscoat, M.S., the research and policy analyst for the UCLA Sustainable Los Angeles Grand Challenge. She selected eleven species based on criteria, including current distribution within the Los Angeles region, their relative threat to native species, and their prioritization by the National Oceanic and Atmospheric Administration (NOAA). A group of biodiversity researchers, including Brad Shaffer, Ph.D., Ryan Harrigan, Ph.D., Tom Gillespie, Ph.D., and Dan Cooper from UCLA's Ecology and Evolutionary Biology department, were consulted by Elizabeth to determine the top 20 most impactful and widely distributed invasive species in the region. This determination was based on quantitative data, when available, and anecdotal evidence based on personal observation from field sites.

We reduced the 20 species recommended by the biodiversity researchers into a list of 11. We did this by selecting those that overlapped with species listed as a priority for NOAA in their Fire and Flow Forum Strategic Plan (Smith et al., 2018). We found six overlapping species: *Sargassum horneri*, red swamp crayfish (*Procambarus clarkii*), zebra mussel (*Dreissena polymorpha*), polyphagous shot-hole borer (*Euwallacea sp.*), New Zealand mudsnail (*Potamopyrgus antipodarum*), and the giant reed (*Arundo donax*). In addition, the Fire and Flow Forum Strategic Plan listed four species that needed more management information. We selected those as our last four species: European starling (*Sturnus vulgaris*), fox squirrel (*Sciurus niger*), black mustard (*Brassica nigra*), pampas grass (*Cortaderia selloana*), fountain grass (*Pennisetum setaceum*).

We conducted a literature review with the following databases: Google Scholar, Web of Science, Otero, and UCLA Library Article Plus. To begin, we used text word searches in the stated databases with keywords pertaining to the species of interest. For example, for the European starling searches, we used the terms European starling and *Sturnus vulgaris*. This was the procedure for all our key species, except for *Sargassum horneri*, because it does not have a common name. We did not use the term, "algae," as it resulted in search results that were too broad for *S. horneri*. Depending on the information we were seeking, we used the following search terms: invasive*, management, management plan*, non-native, impact*, economic*, distribution, ecology. To find information relevant to Los Angeles County, we also used the following terms: California, Southern California, Los Angeles, and Los Angeles County. We also used sources from papers' works cited, resulting from our systematic search. Also, although we did not specifically search through private and public agencies for information, we came across integrated management information from these agencies by using our standard database searches. For example, a majority of our information regarding the European starling was condensed in a research article conducted by the United States Department of Agriculture (USDA) and the California Department of Food and Agriculture (CDFA).

Furthermore, we did not use research papers in languages other than English. We did not exclude papers based on their date of publication in searches for species origin. We did this because the introduction history of an invasive species into California may have been recorded before the 21st century. However, we used sources concerning management plans if they were written after the year 1990 to account for expanding knowledge of repercussions in pesticide and herbicide use. In the case that we used a management plan written before the year 1990, we conducted additional searches to confirm the relevance of the management plan. We limited our searches to papers that were within our required dates of publication, peer-reviewed, and cited more than five times. We also attempted to find multiple articles that agreed with or disagreed

with any data statement that we found relevant. We reviewed a total of one hundred and twenty-two papers in detail and attempted to synthesize commonalities and differences among them.

The last part of our project was to determine the quantity and characteristics of existing invasive species management plans within Los Angeles County. We did this to generate a statistic of how many cities currently have an existing invasive species management plan. To do so, we first compiled a list of cities within the county. From there, we took two routes to determine if the city had an existing management plan for any species. First, to determine public accessibility to management plans, we browsed through city websites and searched for existing plans. If they were not obvious, or easily located under an environmental website tab, we used the city website search bar with the keywords: invasive, management, or non-native. If this resulted in no plan, we conducted a search through Google using the city name followed by “invasive management plan.” To be certain a city did not have a management plan that was simply not public, or updated on their website, we directly contacted every city. We did this via email because we had insufficient time to call 88 cities. We have been recording responses as they have been arriving, and we are making sure that our initial searches align with city email responses. In doing so, we are highlighting the inaccessibility of resources important in biodiversity management within cities. Thus, in creating an integrated management plan for species relevant to Los Angeles County, we will provide a communal resource.

Invasive Species Literature Review

Category 1. Aquatic Species

Sargassum horneri (Algae)

A. Life history

Sargassum horneri is an annual macroalga. Individuals can complete an entire life cycle in less than a year; however, it is possible to have multiple overlapping generations in different life cycle stages in a given season. While native *S. horneri* populations in Asia are dioecious, the invasive *S. horneri* variant in North America possesses androgynous receptacles, meaning that each individual has both male and female gametes. Therefore, a single individual can start a new population (Marks et. al., 2018).

In the eastern Pacific, the majority of *S. horneri* populations follow a consistent seasonal life cycle pattern: recruits appear during spring, and become established during fall. Reproduction takes place during winter and spring. The thalli deteriorate during spring and summer. However, exceptions to this seasonality pattern have been documented in San Diego and Laguna (Wilson, 2014), but details regarding these irregularities were not provided in the report.

a. Identification

Sargassum horneri is a large brown macroalga. Immature specimens have flat, symmetrical, fern-like blades with notched tips. As the alga grows, it becomes loosely branched in a zig-zag pattern, develops small air bladders, and may reach lengths of more than 6m (20 ft). In areas where *S. horneri* becomes invasive, it tends to grow abundantly, forming very thick and nearly impenetrable underwater forests.



Figure 1-1: *S. horneri* examples: (a) distinctive features include alternating fern-like branches with notched tips in a young individual, (b) solid arrow points at air bladders and dotted arrow points at reproductive receptacles in a mature individual; (c) a dense forest of adult *S. horneri*. Photo by Dan Richards (a, b) and Tom Boyd (c).

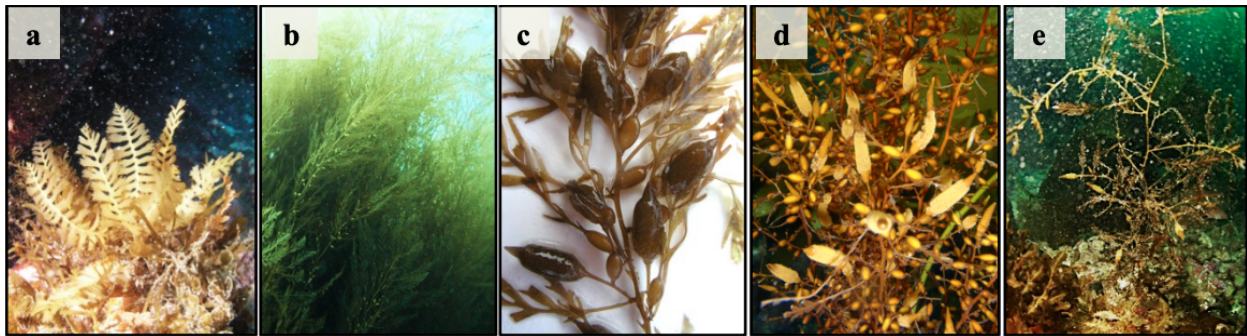


Figure 1-2: Examples of *S. horneri* at different life cycle stages: (a) recruit; (b) immature; (c) mature; (d) fertile; (e) senescent. Photos by Jessie Alstatt (a), Lindsay Marks (b,d), Dan Richards (c,e).

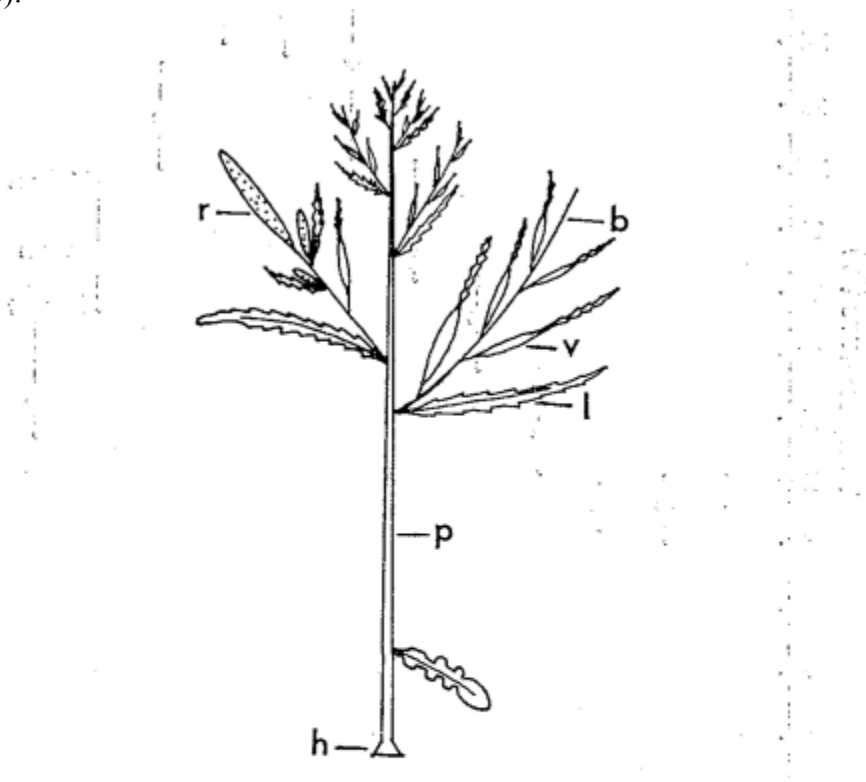


Figure 1-3: Diagram of an *S. horneri* alga: (b) lateral branch; (h) holdfast; (l) leaf, (p) primary lateral; (r) receptacle; (v) air vesicle. Source: Umezaik, 1983.

B. Origin

Sargassum horneri is native to the warm waters off the coast of Korea, Japan, and China, extending to Hong Kong (Uwai, 2009). It grows mainly subtidally, although intertidal populations have been reported (Smith, n.d.; Kaplanis et al., 2016).

C. Current Global/ National Spread

The first time *S. horneri* was detected outside its native region was in 2003, at Long Beach harbor (Miller, 2007). At the time, it was identified as *Sargassum filicinum* by Miller. However, molecular population studies performed by Uwai et al. (2009) merged *S. filicinum* with

S. horneri. Its introduction is believed to have been mediated by trans-oceanic shipping. Vectors include ballast water or hull-fouling (marine growth on the main body of a ship, including the bottom, sides, and deck) on commercial ships or recreational boats (Fofonoff, 2019). The subsequent regional spread is attributed to *S. horneri*'s natural dispersal ability as well as to intentional or accidental removal and release of *S. horneri* by humans). Its air bladders allow it to drift with currents to new sites if detached, and its ability to self-fertilize means that a single reproductive individual could be enough to establish a new population. This colonizing mechanism makes *S. horneri* challenging to contain; the amount of beached alga from this species is second only to *Macrocystis pyrifera* (Miller, 2007). In Southern California, by 2005, *S. horneri* had become commonplace along Terminal Island and both the Ports of Long Beach and Los Angeles. By 2009, it had spread across the Channel Islands and could be found all along the coast of Baja California (Riosmena-Rodríguez, 2012). Since 2013, it has become more dominant on the reefs that have historically been dominated by *M. pyrifera*. As of 2015, its range spans 750 kilometers (466 miles) from Santa Barbara, California to Isla Natividad, Baja California.

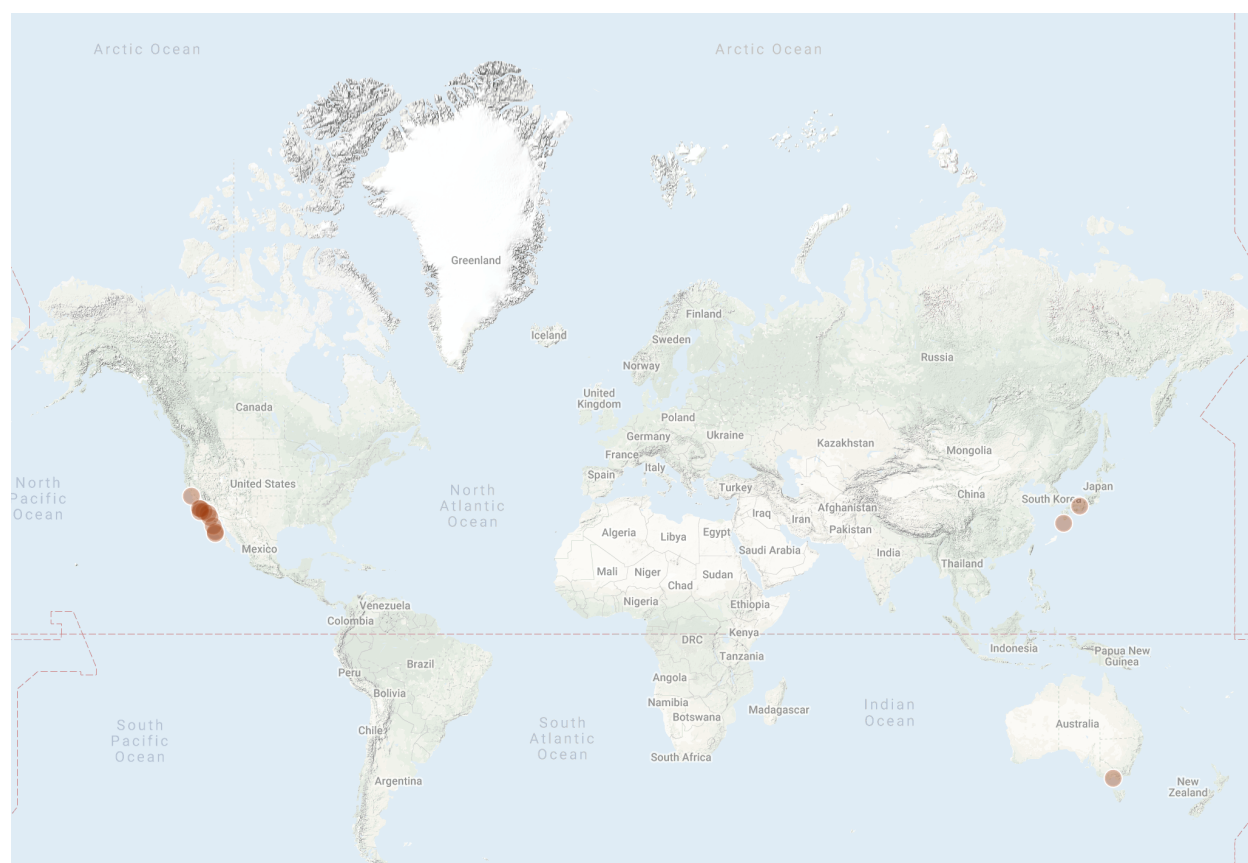


Figure 1-4: Documented sightings of *S. horneri* globally. Source: inaturalist, March 1, 2019.

D. Distribution within Los Angeles County

Within Los Angeles County, by 2005, *S. horneri* had become commonplace along Terminal Island and both the Ports of Long Beach and Los Angeles. Sightings of *S. horneri* wrack, accumulation of detached algal debris on the beach, have been documented at Leo Carrillo State Beach, Malibu State Beach, Pelican Cove, Abalone Cove, Portuguese Bend, Junipero Beach, and Alamitos Bay Landing. Live attached *S. horneri* individuals or populations

have been documented by divers underwater at Little Dume beach, Malaga Cove beach, Pelican Cove and Abalone Cove (“inaturalist”, March 1st 2019).

In Southern California harbors, *S. horneri* is abundant on riprap walls within harbors, but it is rare on exposed jetties outside harbors, or on exposed coastlines. The extent to which it uses human-made structures is unclear, but it has been found on a seawater intake pipes (Miller et al., 2007) and on fouling panels (Woods Hole Oceanographic Institution, 1952).

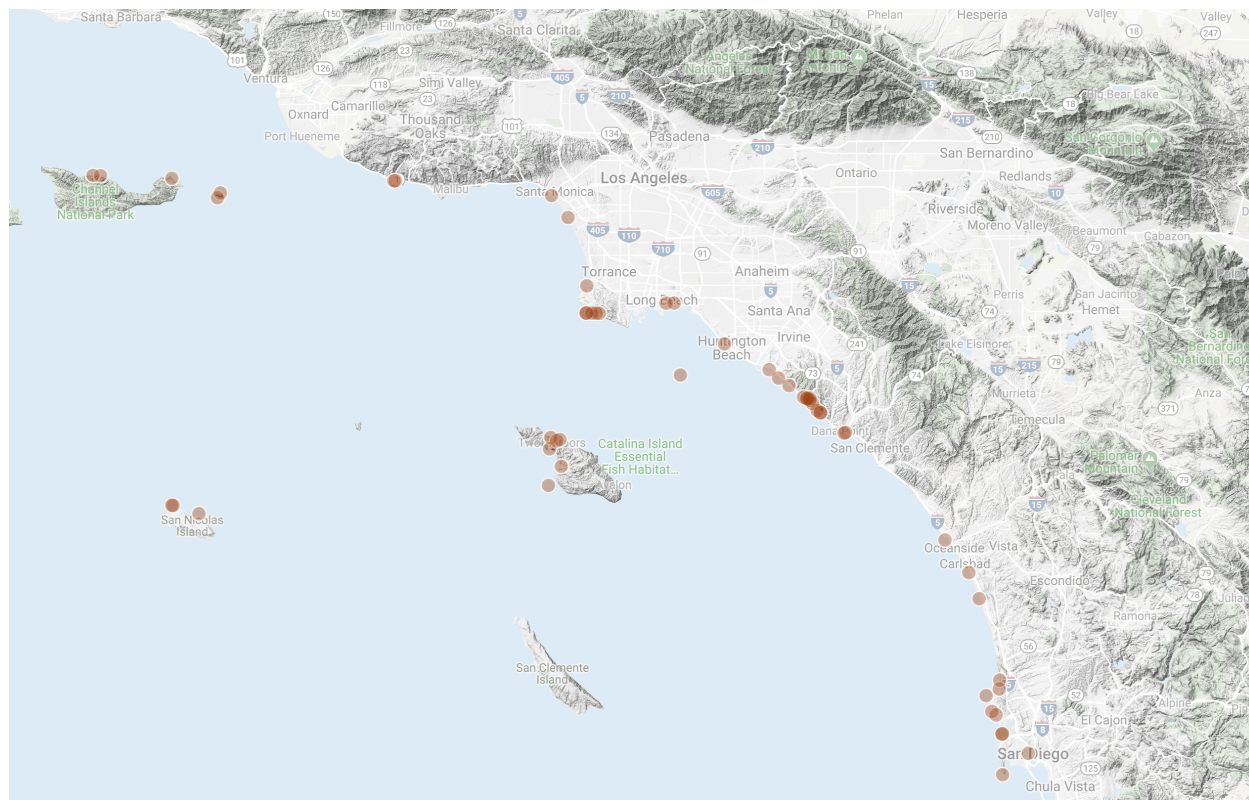


Figure 1-5: Documented sightings of *S. horneri* around Los Angeles County. Source: inaturalist, March 1st 2019.

E. Ecological Impact

Information on the ecological impact of *S. horneri* is limited; however, what is known is based mainly on qualitative observations by divers (Bushing, 2014). Broadly speaking, *S. horneri* competes with native species, causes changes in habitat, affects food and prey dynamics, and impacts the aesthetic aspect of marine life underwater.

Competition with native species: Observations made by divers at Catalina Island show that *S. horneri* outcompetes native seaweeds and *M. pyrifera*. The dense mats that *S. horneri* forms are thought to shade out germlings of native seaweeds. Invasion by *S. horneri* is observed during periods of warmer water temperatures but halted during the winter when water is cooler (Bushing, 2014). Research conducted in three marine protected areas (MPAs) on the coast of Anacapa Island has shown that in the oldest MPAs, which have better-preserved kelp forests, the native algal communities resisted the invasion of *S. horneri*. On the other hand, in the newest MPAs and in unprotected areas, which experience more fishing of sea urchins, *S. horneri* invasion was more successful (Caselle et al., 2017).

Food and prey dynamics: Polyphenols, the toxins produced by *S. horneri*, deter native herbivores from grazing on this algae. Instead, herbivore feed on native algae, tipping the competitive scale in favor of *S. horneri* (Bushing, 2014).

Habitat change: *S. horneri* has the potential to be a significant habitat engineer because of its rapid growth and large size (Fofonoff, 2019). Dense growths of *S. horneri* may inhibit the movement and feeding of fishes and spiny lobsters (*Panulirus interruptus*) (Bushing, 2014).

Aesthetic: Dense growths, decaying fragments, and gametes of *S. horneri* limit visibility and enjoyment of SCUBA divers (Bushing, 2014).

F. Human Health Impact

While there is no published research specifically exploring the human health impact of invasion by *S. horneri*, we do know that it is outcompeting *M. pyrifera* in areas where it is invasive. *M. pyrifera* provides many ecosystem services; its role as a buffer of storm and wave action is particularly relevant to people living in coastal cities. The loss of *M. pyrifera* will impact populations living in coastal cities or islands, as well as people who depend on fisheries for food or resources.

G. Economic Cost

The loss of kelp forests has downstream effects, impacting commercially and recreationally important fished species which depend on kelp for food or habitat, like sea urchins and kelp bass (NOAA, 2019). The forests are also critical habitat for many species of indigenous biodiversity. Their loss has an indirect cost to the coastal economy in the form of recreational activities associated with ecotourism.

The increase in prevalence and thus biomass of the various invasive *Sargassum* species has spurred interest in its commercialization for food, fuel, and pharmaceutical applications. This could generate enough resources to fund cleanup efforts and offset the economic cost of this family of invasives (Milledge and Harvey, 2016).

H. Best Management Practices

Research conducted by Marks et al. (2016) compared several approaches for clearing *S. horneri* from rocky reefs off Santa Catalina Island, California and investigated the ecology of *S. horneri* to determine the best strategy to control it.

The researchers assessed the efficacy of removal of *S. horneri* as a method of eliminating or reducing colonization and survivorship of this invasive species. Circular experimental plots measuring 60 square meters were cleared of *S. horneri* using two different removal methods. One method relied on a suction device, and the other relied on a line and bag strategy. Control plots, where no *S. horneri* was removed, were also assessed. The researchers found that the method with maximum efficiency, defined as biomass removed per worker per hour, varied based on the number of divers and surface support workers. It is important to note that the removal of *S. horneri* with the aid of the underwater suction device allows only two scuba divers to work at a time and had significant startup costs as well as logistical challenges. On the other hand, the line and bag method, while less technologically sophisticated, allows more workers to be involved and requires significantly less resource and training. Results showed that the removal of *S. horneri* in early winter, right before the onset of reproduction, reduced recruitment in the following generation by an average of 54%, and it reduced survivorship to adulthood by an average of 25%.

Moreover, to determine whether the removal of entire individuals is required in the efforts to manage *S. horneri*, the researchers severed the stipes (for reference, view figure 1-3) of individual alga and assessed their ability to regenerate and grow from the remnant holdfast. No evidence was found that alga with severed stems can regenerate, suggesting that control of *S. horneri* via removal does not require removal of all living tissue.

In conclusion, the data suggest that removal of *S. horneri* can be optimized if performed on areas larger than 60 square meters, and during periods where water temperatures tend to be cool in order to favor growth of native algae. Recently invaded areas where *S. horneri* has not yet become widely established should be prime targets for such intervention.

The likelihood of eradicating *S. horneri* is bleak. While it was a possibility at the onset of the invasion in 2003, the current abundance of *S. horneri* coupled with its high capability to spread means that it is virtually impossible to eradicate it (Miller pers. comm., 2015).

In a recent personal communication with Lindsay Marks (2019), discussing the best methods for controlling *S. horneri*, she informed us that the removal of *S. horneri* as a method of management is only appropriate in certain situations. First, removal should be performed in old MPA's where native kelp populations are established and can colonize the cleared areas after removal of *S. horneri*. Second, removal should be performed during the fall, in order to target the plants before they become reproductive. Finally, removal should be performed during years when water temperatures are relatively cool, to favor the growth of native kelp. Otherwise, the best methods of management of *S. horneri* are preventative measures targeting vectors to avoid further spread of this invasive species. These measures are especially crucial at harbors, where *S. horneri* can spread via ballast water or by attachment to commercial or recreational boats.

A set of fliers designed by California Sea Grant outlines guidelines for boaters and divers to limit the risk of spreading invasive seaweeds, including *S. horneri*, from harbors and infested areas. The recommended guidelines for boaters include cleaning the hull before leaving the harbor and removing seaweed fragments from the anchor, lines, and boat decks before moving to new locations. The recommended guidelines for divers include diving in uninfested sites first and then removing seaweed fragments from themselves, their gear, and their boat deck before moving to new locations (California Sea Grant, 2019).

Procambarus clarkii (Crayfish)

A. Life history

Procambarus clarkii is a freshwater crayfish that is tolerant to a wide range of aquatic environments, including rivers, lakes, ponds, streams, canals and seasonally flooded swamps and marshes (Gherardi et al., 2000). *Procambarus clarkii* employs an r-strategy, with a short life cycle and high fecundity (Gherardi et al., 2000); a female can produce between 100-500 eggs at one time. Newly hatched *P. clarkii* stay in the burrow for eight weeks before they can fend for themselves (Riley et al., 2005). The species is an opportunistic omnivore, with a primarily plant based diet (Riley et al., 2005). *Procambarus clarkii* shows two patterns of activity; a wandering phase and a stationary phase. The wandering phase, characterized by short peaks of high locomotion, involves behaviors such as fighting, mating, and foraging. These take place during dusk and through night. Males move up to 17 km in four days to breed, which is a significant contribution to the dispersion for the invasive species. The stationary phase is during the day when *P. clarkii* hide in their burrows (Gherardi et al., 2000).

a. Identification

The size of adult *P. clarkii* varies between 6 cm-12.5 cm long (Gherardi et al., 2000). *Procambarus clarkii* are dark red in color, smaller *P. clarkii* can be light brown, and they are covered with black and white spots (Riley et al., 2005). Features to identify the *P. clarkii* are bumps on its claws and the inside margin or the edge of the claw's palm has a forward pointed sawtooth-like bumps. *Procambarus clarkii* have lines, and ridges on the back between the head and tail that join or touch in the middle of the back (Riley et al., 2005).



Figure 2-1: Identification of the *P. clarkii*. (Photo by Scott Loarie, iNaturalist, 2019).

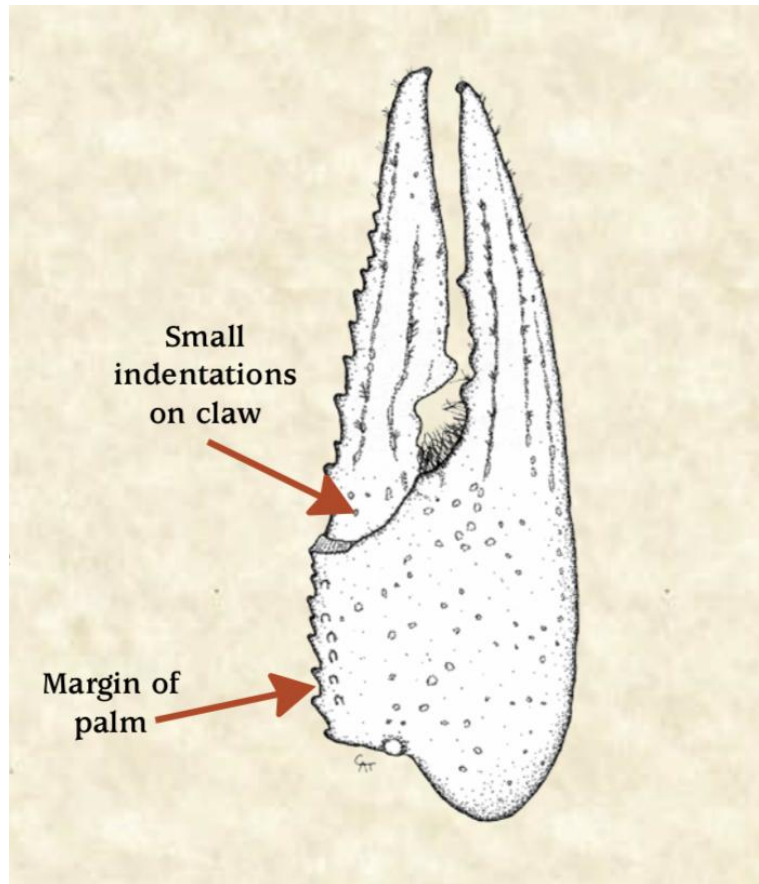


Figure 2-2: *Procambarus clarkii* claw anatomy (Source: Riley et al., 2005).

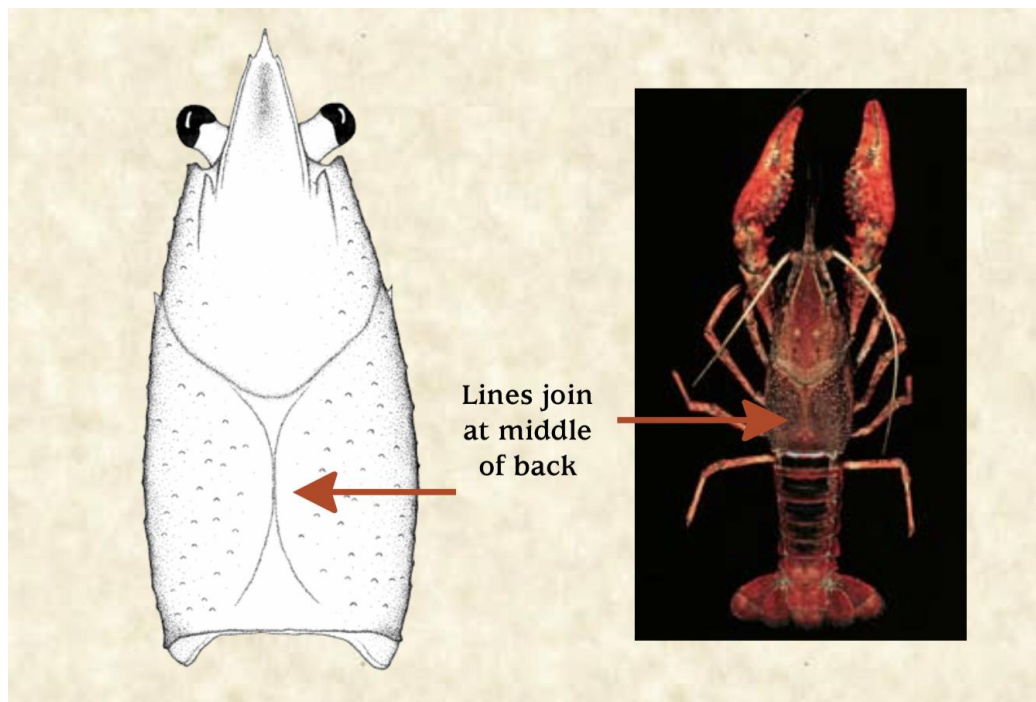


Figure 2-3: *Procambarus clarkii* back anatomy (Source: Riley et al., 2005).

B. Origin

Procambarus clarkii originated in the Southeastern United States and northeastern Mexico (Riley et al., 2005). The ability for *P. clarkii* to grow and mature rapidly contributed to the popularity of *P. clarkii* as a food item and a source of fish bait, spreading the invasive species nationally (Kerby et al., 2005). Releasing *P. clarkii* as pets also contributed to the introduction of this species to Southern California (Riley et al., 2005). *Procambarus clarkii* was introduced to Italy through aquaculture enterprises and is a significant source of income for many people (Gherardi et al., 2000).

C. Current Global/ National Spread

Procambarus clarkii is native to southeastern United States and has spread throughout the nation, reaching the County of Los Angeles. It has also spread through other countries including Japan, Italy, Portugal, and Germany (Gherardi et al., 2000).

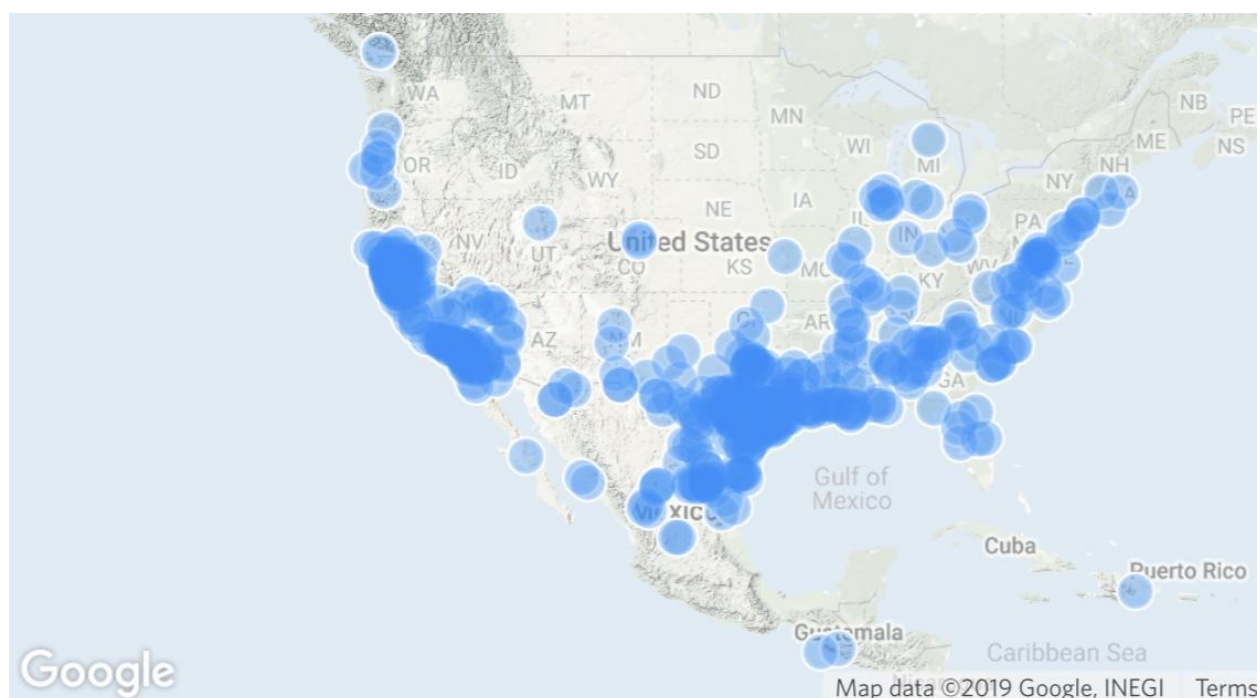


Figure 2-4: Distribution of invasive *P. clarkii* in the United States of America. Source: inaturalist.

D. Distribution in Los Angeles County

Procambarus clarkii is distributed among freshwater ponds, streams and 3 creeks of the Santa Monica Mountains and prevails over the whole watershed area of Los Angeles County, including the Malibu Creek watershed (Li, 2015).

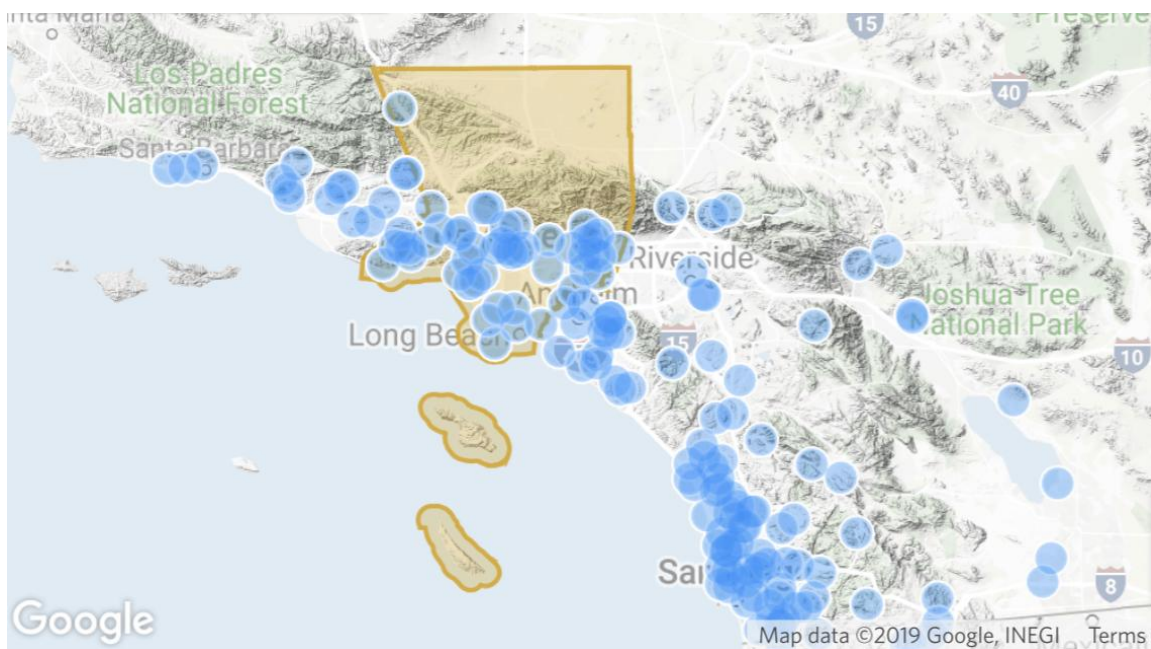


Figure 2-5: Distribution of *P. clarkii* in Los Angeles County. Source: inaturalist, March 1st 2019.

E. Ecological Impact

The success of this invasive species can be explained through its life history traits, such as its rapid growth, high fecundity and its disease resistance (Gherardi et al., 2000).

Procambarus clarkii is an aggressive species and can threaten native amphibians such as the California red legged frog, the Pacific treefrog and can affect newt reproduction (Riley et al., 2005). Gamradt et al. (1997) studied the aggressive behavior of *P. clarkii* in Trancas Creek in Los Angeles County. *Procambarus clarkii* attacked or harassed adult newts, affecting newt courtship and mating, thus having the potential to decrease or eliminate newt reproduction (Gamradt et al., 1997). These ecological impacts of *P. clarkii* deplete the abundance of the native species and alters the natural balance of the ecosystem and the community structure (Colgan, 2018).

F. Human Health Impact

Procambarus clarkii indirectly increase the populations of mosquitoes which are vectors of disease. Mosquitoes can spread diseases such as malaria, Zika and West Nile virus (Colgan, 2018). These diseases can have health impacts on the ecosystem and the surrounding residential communities. The invasive *P. clarkii* preys on the dragonfly nymph, which are predators to mosquitoes (Bucciarelli et al., 2018). Therefore, if *P. clarkii* drive the dragonfly nymph population down, they will increase the abundance of mosquitoes. The disruption of the native predator-prey relationship has been explored in the Santa Monica Mountains (Bucciarelli et al., 2018).

G. Economic Cost

Procambarus clarkii has a significant economic cost from its ecological damage to native environments. This affects in the agriculture, forestry and fishery sectors (Loureiro et al., 2015). For example, *P. clarkii* has caused damage to “drainage systems because of its burrowing

activities which has consequently had an effect on rice yield” (Loureiro et al., 2015). *Procambarus clarkii* is problematic for fisheries by damaging fishnets, spoiling valuable fish caught (Loureiro et al., 2015).

H. Best Practices

Management options against the invasive *P. clarkii* include; drainage of ponds, using biocide as well as biocontrol and barriers (Kerby et al., 2005; Loureriro et al., 2015). Kerby et al. (2005) explains that research has not yet identified a successful prevention of the spread of the invasive *P. clarkii*.

Using biocides, such as xenobiotics, organophosphate, organochlorine and pyrethroid insecticides, were shown to be ineffective (Loureriro et al., 2015). This was because of the insecticides selective efficiency depending on the size of the individual *P. clarkii*. The small *P. clarkii* are more susceptible to this treatment. In addition, the lack of specificity of the chemical methods have devastating impact on native species, doing more harm than good. Chemicals cause bioaccumulation and biomagnification down the multiple food chains of the whole ecosystems.

Biocontrol against *P. clarkii* involved other aquatic life that act as predators such as eels, burbot, perch and pike (Loureriro et al., 2015). This also poses a risk to the ecosystem due to the lack of specificity of the biocontrol and the creation of a new invasive species, posing an increased threat (Loureriro et al., 2015).

Gherardi et al. (2000) emphasised the importance of understanding the individualized behavior of *P. clarkii* to target effective management. Kerby et al. (2005) responded to this and identified the streams with large barriers, including waterfalls and culverts, in the Santa Monica Mountains of Southern California often did not have the invasive *P. clarkii* present upstream of the barrier. The barriers were shown to reduce movement of *P. clarkii* between pools. In addition, large flow events are likely to increase passive movement downstream and reduce movement upstream. A study on *P. clarkii* in Germany found a pipe on a brook off the river Rhine inhibited the upstream invasion of *P. clarkii* (Renz and Breithaupt, 1999). The study concluded that the main effective management strategy at the time was channelling and obstructions to flow ways (Renz and Breithaupt, 1999). Kerby et al. (2005) mentions that a loss of connectivity in streams would have an impact on reducing the number of *P. clarkii*. However, the environmental benefits of applying the removal of *P. clarkii* needs to be weighed up against the environmental costs. Barriers are damaging to native aquatic species and a lack of connectivity is one of the major cause of ecosystem decline in riparian systems (Loureriro et al., 2015). This explains why barriers are an effective management strategy to decrease the *P. clarkii* population, however, the trade-off is the native amphibian and aquatic species populations.

A study done by Kerby et al. (2005) suggested the most effective management strategy would be to focus on smaller stream segments that are bound by a natural downstream barrier and that removal efforts of *P. clarkii* in that segment are timed with large flow events. Heavy rains in 1995 resulted in the removal of *P. clarkii* from one stream in the Santa Monica Mountains of Southern California (Gamradt and Kats, 1996). This resulted in an increase of native newt biomass in the stream with the absence of *P. clarkii* (Gamradt and Kats, 1996). Physical removal efforts have not achieved complete eradication but have shown lower numbers of *P. clarkii*, which appeared more achievable and had high capture rates in shallow streams (Kerby et al., 2005).

Physical removal efforts alone can be limited in effectiveness because *P. clarkii* span over such a large area (Li, 2015). Physical removal efforts include the use of traps, fyke and seine nets, line fishing and electro fishing (Kerby et al., 2005). A fyke net is a cone shaped mounted bag net that is mounted on a rigid structure and is most effective in shallow waters (Li, 2015). *Procambarus clarkii* would enter voluntarily and be trapped coming out. Whereas a seine net hangs vertically in the water with the two ends creating a circular shape. There are floats on the top and weights on the bottom edge which encircle the *P. clarkii*. Bait, such as roach, bream or bleak may increase the number of *P. clarkii* caught in these traps (Riley et al., 2005).

Preventing the spread of *P. clarkii* is another imperative management strategy that needs to be addressed. For example prohibiting the transportation of live *P. clarkii* will help decrease their invasion further afield (Gherardi et al., 2000). Encouraging public education and awareness of the negative ecological, economic and health impacts of *P. clarkii* could increase the accountability of using the invasive species as bait for fishing, food, pets and aquaculture (Riley et al., 2005).

Category 2. Terrestrial Animals

Sturnus vulgaris (European starling)

A. Life History

Sturnus vulgaris (European starling) is a bird that has become a widespread invasive species because of its ability to adapt to the urban environment and outcompete native birds (Axelson et al., 2017). As an urban bird, it does not typically live in unbroken stretches of forest, chaparral, or deserts (Axelson et al., 2017). In urban areas, they often use mowed lawns, city streets, and agricultural fields for foraging (Axelson et al., 2017). *Sturnus vulgaris* feeds on a variety of insects, fruit, grains, livestock feed, and household trash (Axelson et al., 2017). They build their nests 10-25 ft above the ground on trees, but they can also nest in building cavities, streetlights, and nest boxes (Axelson et al., 2017). They make their nests out of grass, feathers, trash, cloth, and they add fresh green plants during nesting season in the summer months (Axelson et al., 2017). When they are breeding, they can have one to two broods and lay between three to six eggs (Axelson et al., 2017).

a. Identification

According to Axelson et al. (2017), *S. vulgaris* is a small and stout bird with a short tail and long slender beak. They are approximately 20 to 23 cm in length, with a wingspan of 31 to 40 cm. During the summer breeding season, their plumage is mostly all black with purple-green iridescence and a few white spots found dorsally. During the non-breeding winter season, their plumage is black with an abundance of white spots found dorsally and ventrally. As a juvenile, *S. vulgaris* is pale brown in plumage with a darker bill. However, within a juvenile's maturing plumage, there may be signs of black coloration and developing white spots.



Figure 3-1: A non-breeding *S. vulgaris* photographed in Alhambra, CA. There are white spots dorsally and ventrally on plumage. (Photo by Jmaley, iNaturalist)



Figure 3-2: A breeding *S.vulgaris* photographed in Georgia. There are no white spots on ventral plumage. (Photo by Dan Vickers, Macaulay Library)



Figure 3-3: A juvenile *S.vulgaris* photographed in Illinois. (Photo by Walter Marcisz, Macaulay Library)

B. Origin

Sturnus vulgaris is native to Europe, Southwest Asia, and North Africa, but it is currently found on every continent except Antarctica (Rollins et al., 2009). They were first introduced to the United States in 1890 when a civilian released 100 *S. vulgaris* into Central Park, New York (Linz et al., 2018; Kessel, 1953). Out of those 100 released birds, 32 survived and were able to disperse throughout the United States, reaching the West Coast in 1942 (Linz et al., 2018; Kessel, 1953). This is genetically shown in studies conducted by Cabe (1999), where he determined that populations of *S. vulgaris* throughout North America are genetically homogenous, and thus, a single panmictic population. Specific to California, *S. vulgaris* was first spotted in Tule Lake in 1942 (Kessel, 1953). The bird traveled to Southern California, where it was first spotted in Los Angeles County in the cities of Whittier and Pasadena in the 1950s (Kessel, 1953).

C. Current Global/ National Spread

The current range of *S. vulgaris* in the Americas includes the United States from Florida to Alaska, Mexico, Canada, the Bahamas, Central America, the Yucatan Peninsula, Puerto Rico, Jamaica, and Cuba (Linz et al., 2018; Linz et al., 2007; Kessel, 1953). In Europe, *S. vulgaris* is found from Norway to Spain and south in the Canary Islands (Feare & Franssu, 1992). The species is also found in South Africa, New Zealand, and Australia (Linz et al., 2007). *Sturnus vulgaris* has a native home range in Europe, parts of Asia, and North Africa (Rollins et al., 2009). Rollins et al. (2009) also details that, due to this extensive range, *S. vulgaris* is considered one of the most damaging invasive species worldwide.

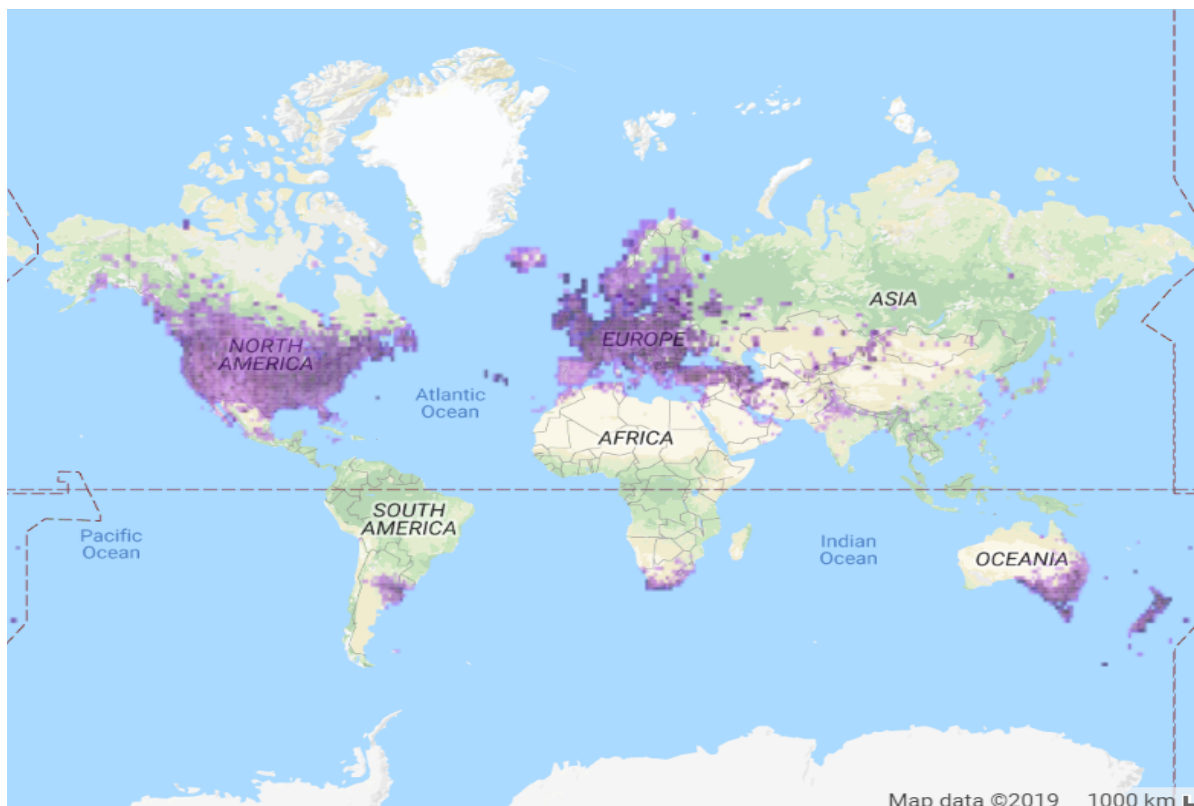


Figure 3-4: The global spread of *S. vulgaris* depicted in purple. (Source: Cornell Lab of Ornithology)

D. Distribution in Los Angeles County

Sturnus vulgaris first appeared in Los Angeles County in 1950 in the cities of Whittier and Pasadena (Kessel, 1953). Current information on exact habitats within Los Angeles County has not been documented in research articles; however, organizations, such as the Natural History Museum in Los Angeles County, confirm that *S. vulgaris* is a species that is still found in abundance throughout the county. A study performed by Royall et al. (1972) banded 1,192 *S. vulgaris* birds within Los Angeles County, although locations within the county were not specified. This revealed that within Southern California, Los Angeles County had the largest population of *S. vulgaris*. Second to Los Angeles was San Bernardino County with 1,031 bandings. In addition, public sources on iNaturalist revealed 415 observations of *S. vulgaris* as of March 15th, 2019. It is important to note that the observations may have been of individual birds, or of a flock.

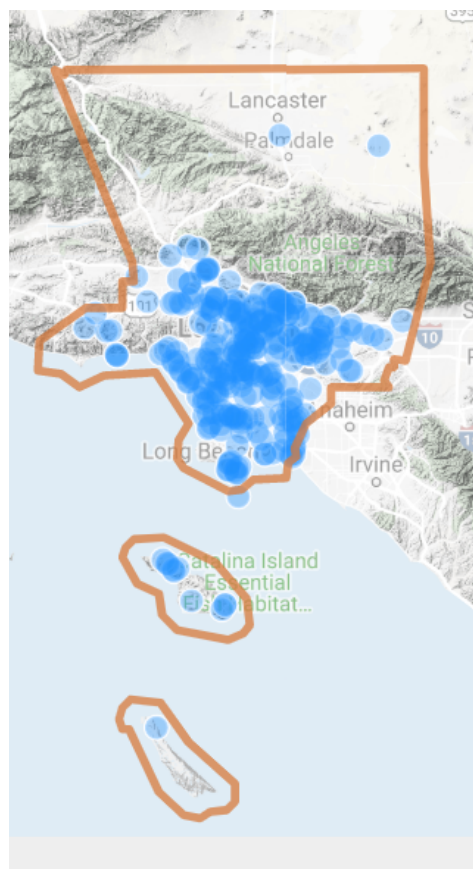


Figure 3-5: Map of Los Angeles County, CA with blue dots indicating observations of *S. vulgaris* by users on iNaturalist. (Source: iNaturalist, March 15, 2019).

E. Ecological Impact

Sturnus vulgaris can nest in trees, buildings, and nest boxes (Axelson et al., 2017; Linz et al., 2018). They can outcompete native bird species that nest in nest boxes, such as the wood duck (*Aix sponsa*) and the western screech owl (*Megascops kennicottii*) (Linz et al., 2018; Pimentel et al., 2004). They can evict cavity-nesting birds if the entry hole of the nest has a diameter larger than 3.97 cm. (Linz et al., 2018). Some native species, like *M. kennicottii*, may require a larger nest box entry diameter due to their larger body size (Linz et al., 2018). As a

result, there must be regular monitoring and nest cleaning to prevent *S.vulgaris* from invading the nest (Linz et al., 2018). This may result in a decrease of native species due to ecological competition that may force native birds to delay breeding within a season (Koenig, 2003). The aggressive nesting behavior of *S.vulgaris* has resulted in a decline of great spotted woodpeckers (*Dendrocopos major*) in England and nuthatches (*Sitta europaea*) in the Netherlands (Smith, 2006).

F. Human Health Impact

Sturnus vulgaris is responsible for the transmission of 25 diseases, such as parrot fever and avian salmonellosis, which are transmissible to humans, livestock, and poultry (Linz et al., 2018; Pimentel et al., 2004). They may carry *Salmonella enterica*, which can be deposited into livestock animals' water troughs and feed (Carson et al., 2012; Linz et al., 2018). Consequently, *S.enterica* in contaminated livestock threatens human health because it is a foodborne pathogen that results in over one million clinical illnesses a year (Linz et al., 2018). Moreover, according to the Center for Disease Control and Prevention (CDC), West Nile virus is the leading cause of mosquito-borne disease in the continental United States, which can be transmitted by numerous vectors, including *S.vulgaris*. West Nile virus has been found in Los Angeles County (Kluh et al., 2010). Between 2004 to 2008, Kluh et al. (2010) tested dead birds for West Nile virus in Los Angeles County and found 51 infected *S.vulgaris*.

G. Economic Cost

Sturnus vulgaris threaten agricultural regions in the United States because they can disrupt crop production (Pimentel et al., 2004). This affects farmers who grow costly produce, such as cherries and grapes, because these fruits primarily make up the species' diet. Specifically, the bird can destroy \$2,000 worth of cherries, and \$6 worth of grain, per hectare of land (Pimentel et al., 2004). In the United States alone, total economic loss due to *S. vulgaris* amounts to about \$800 million per year (Pimentel et al., 2004). This is particularly important in California, being that California is the fourth largest grape producer in the world (Dunham, 2016). Los Angeles contributes to California's wine economy in being responsible for 79 acres of grape cropland out of California's total of 827,000 acres (Silbert, 2001). However, numbers have not been calculated for the exact economic toll that *S. vulgaris* takes on California's wine grapes and cherries.

H. Best Management Practices

There are different approaches that can be taken to manage the invasion of *S.vulgaris*, yet, none of the management practices are specific to Los Angeles County. However, Linz et al. (2018), as part of the United States Department of Agriculture (USDA), created an integrated *S. vulgaris* management plan that can be implemented across various regions, including Los Angeles County.

Non-Lethal Management:

- (1) Berge et al. (2007) conducted a study in northern California grape fields to determine the efficacy of frightening devices for birds in crop fields. They found that loud noises, specifically recorded distress calls of *S. vulgaris*, can significantly reduce the bird populations within valuable crop fields. According to Berge et al. (2007), implementation of broadcast calling units in Pinot noir vineyards in California saved farmers \$700 per

hectare of wine grapes. Other frightening devices of varying efficacy can be used, such as battery-operated alarms, animated scarecrows, bright lights, propane exploders, and hawk kites (Linz et al., 2018). The use of frightening repellants functions best if they are used during *S. vulgaris*' foraging periods, which occur during the early morning and late afternoon (Linz et al., 2018).

- (2) Linz et al. (2018) also stated that adding methyl anthranilate, a common food additive, onto cherry and grape crops can function as a chemosensory repellent. Methyl anthranilate causes irritation to pain receptors associated with the trigeminal nerve in the mouth and nostrils of birds; however, it is not lethal to the birds. Askham (1992) conducted a study to determine the effectiveness of methyl anthranilate as a pesticide on cherries, grapes, and blueberries. The authors found that *S. vulgaris* refused to eat the treated fruits, resulting in a positive cost-benefit ratio for farmers. Methyl anthranilate needs to be applied in high concentrations, between 5000 ppm to 10,000 ppm, to act as a reliable chemosensory repellent. Additionally, because methyl anthranilate degrades rapidly in the environment and solubilizes in rain, multiple applications may be needed to deter *S. vulgaris*. Despite being a non-lethal chemical, users should be aware of any potential environmental threats of methyl anthranilate.
- (3) Furthermore, exclusion tactics can be used as another non-lethal management approach for *S. vulgaris* (Linz et al., 2018). Exclusion tactics are physical barriers that can prevent *S. vulgaris* from nesting and foraging. This requires the use of nylon or plastic netting, which can be placed over the following: crops, barns, ledges on multi-story buildings, and other common perch and foraging sites. Wood, metal, or Plexiglass can be used as an alternative to nylon or plastic netting. This works if placed at a 45°-angle when covering ledges used for perching, nesting, or roosting. For agricultural use, plastic netting can be placed over crops to prevent damage to fruit. This method proves to be cost-effective for preventing damage to high-value wine grapes.



Figure 3-6: Plastic netting over wine grapes. (Source: Linz et al., 2018)

Ultimately, these are all non-lethal options that provide relatively short-term relief. To maximize the efficiency of repellent tactics, the three listed methods should be used in alternation to prevent *S. vulgaris* habituation. For example, a flock of *S. vulgaris* may be able to recognize an auditory repellent as harmless if it is repeated too frequently. Thus, it is

recommended to use an integrated approach that combines frightening repellants, exclusion tactics, and chemosensory repellants (Linz et al., 2018). Overall, due to the extent of *S. vulgaris*, Feare and Franssu (1992) stated that non-lethal methods are likely the most effective management plan to achieve lasting damage reduction.

Lethal Management:

- (1) Linz et al. (2018) described the use of Starlicide, also known as DRC-1339, as an effective lethal pesticide specific to *S. vulgaris*. Starlicide is usually less toxic for other bird species because birds have varying sensitivity to the DRC-1339 compound. *Sturnus vulgaris* is very sensitive to DRC-1339 and may die in a single treatment after one to three days (Eisemann et al. 2003). In addition, Eisemann et al. (2003) determined that Starlicide treated *S. vulgaris* do not pose a trophic-level threat to scavengers or predators. This is because DRC-1339 is metabolized and excreted rather quickly. However, it is unclear if DRC-1339 poses any environmental threats, so the use of Starlicide should be minimal.
- (2) In addition, *S. vulgaris* may be trapped in accordance with state or local laws. Using nest boxes with added traps is useful in areas with a high density of *S. vulgaris*. To house *S. vulgaris*, a trap must be 6.25 inches wide, 6.75 inches deep, and 15.25 inches high (Kessel, 1957; Knittle & Guarino, 1976). The entry hole must be 1.75 inches in diameter with an added external trap door (Knittle & Guarino, 1976). The trapped bird should then be euthanized. This may be a better solution to using a chemical with unknown environmental trade-offs; however, trapping *S. vulgaris* may be time-consuming and result in varied success (Linz et al., 2018).
- (3) Moreover, *S. vulgaris* may be killed by hunting in accordance with state or local laws. Hunting *S. vulgaris* may also indirectly serve as an auditory repellant tactic for surviving birds (Linz et al., 2018). However, shooting may be labor intensive and requires physical skills.

Sciurus niger (fox squirrel)

A. Life history

Although *Sciurus niger* (fox squirrel) can mate at any time during the year, it reaches its peak reproductive period during the months of December and June (New Hampshire PBS, 2019). While *Sciurus griseus* (western gray squirrel), a species of squirrel native to Los Angeles County, reproduces once a year, with an average expectancy of 2.2-3.0 progeny (Carraway & Verts, 1994), *S. niger* tends to reproduce twice a year with a slightly more plentiful output of 1.97-3.35 progeny each time (Koprowski, 1994). This results in a rapid increase in the *S. niger* population, as they multiply exponentially. *Sciurus niger* young are born blind and without any fur. They are not independent until they reach an age of three months. They are able to open their eyes at five weeks, ingest food at eight weeks, and climb down trees after ten weeks (New Hampshire PBS, 2019). In their regions of origin, they are primarily found occupying deciduous forests and prairies. However, upon their introduction to the west coast, they now inhabit urban areas with high population densities (Wolf & Roest, 1971; Steele & Koprowski, 2001). This change can be explained by the fact that *S. niger* is better equipped than *S. griseus* to deal with the destruction of habitats caused by city development. As a result, they are able to invade and occupy areas that were inhabited by *S. griseus* prior to these changes. Trends of squirrel

abundance following events of habitat destruction were studied over long periods in the midwest and show that *S. griseus* populations decline, while *S. niger* populations increase significantly (Allen, 1943; Nixon et al., 1978). Therefore, their ability to occupy regions that have been tampered with, often by human development of infrastructure, is characteristic of this species. This trend is observed both in their native regions, as well as regions to which they have been introduced.

a. Identification

Sciurus niger is the largest tree squirrel, with a length of 10-15 inches. Depending on its geographic location, its color pattern varies. Within the western part of its range, the dorsal side of its body is grayish in color, with more of a rust colored coat covering its underside (New Hampshire PBS, 2019).



Figure 4-1: Adult *S. niger*. (Source: Jan Dauphin, 2015).

B. Origin

Sciurus niger originated from the eastern coast of North America (Koprowski, 1994).

C. Current Global/ National Spread

From its native, highly vegetative, environment in the eastern and central states of the U.S, west to the Dakotas, Colorado, and Texas (New Hampshire PBS, 2019), *S. niger* is now found in many urban regions within the west including California, Washington, Oregon, Idaho, Montana, Wyoming, Colorado, and New Mexico. They are present in British Columbia and Ontario, Canada as well (Flyger & Gates, 1982; Jordan & Hammerson, 1996). Lastly, they have also been spotted in regions of Northern Mexico (Fahey, 2001).

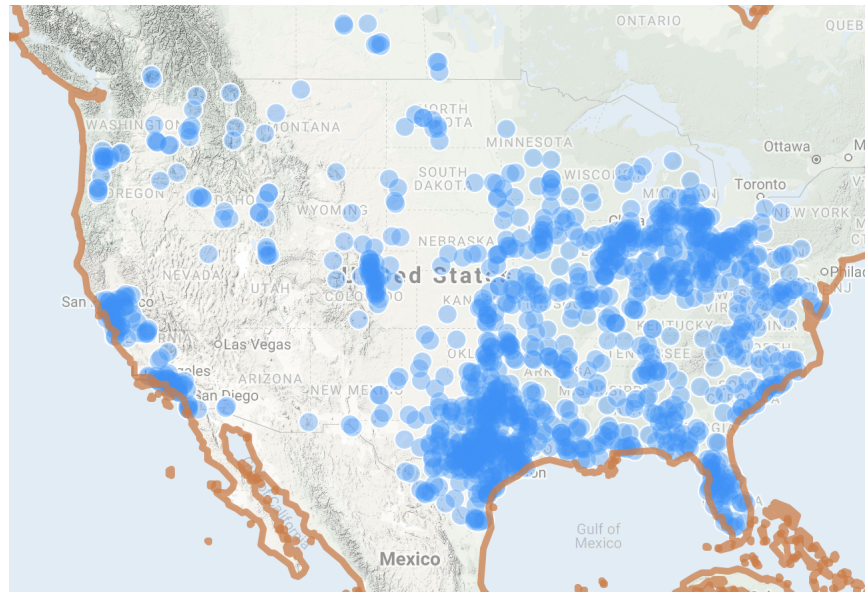


Figure 4.2: Observations of *S. niger* throughout North America indicated with blue dots by users on iNaturalist (Source: iNaturalist, March 1st 2019).

D. Distribution in Los Angeles County

Sciurus niger was originally introduced to Los Angeles County in 1904. The first group of these organisms that invaded Los Angeles originated from the Veteran's Hospital in West Los Angeles. These animals were released by the senior citizens residing at the hospital, and freely spread outward from Los Angeles (Becker & Kimball, 1947). They were brought to the hospital from a region neighboring the Mississippi Valley (Becker & Kimball, 1947). After their introduction, they generally occupied urban and suburban areas densely populated with humans; however, with continuous expansion in range, they crossed over into foothill areas, joining the native *S. griseus* (Hoefler & Harris, 1990; Ingles, 1954). A portion of the *S. niger* population in Los Angeles County can be traced back to the southern prairie lands of Canada, located south of approximately forty-eight degrees north latitude (Koprowski, 1994). A subspecies of *S. niger*, *S. niger rufiventer*, can be found in the Midwest, specifically adjacent to the Mississippi Valley, between southern Illinois and central Tennessee (Hall & Kelson, 1959). This is the subspecies that was introduced into Los Angeles and can now be found throughout all of California (Moncrief et al., 2010; Claytor et al., 2015).

Following its introduction at the Veterans Hospital, *S. niger* spread profusely from Sawtelle, which is located at the intersection of Wilshire and Sepulveda boulevard. From there they spread to the intersection of Woodbend Drive and Iowa Court, Claremont. This spread occurred at a rate of 0.7km/year, for 99 years, from when this data was recorded (King, 2010). They also spread northwest from this point, towards Ventura County. Southward movement towards San Pedro was also recorded over a span of 94 years, while a northward expansion to Saugus was documented over a 74-year span (King, 2010).

them. (Muchlinski et al., 2009). Their ability to replace these native squirrels is independent of any physically dominating behavior, because they do not pose any directly harmful threats through aggressive actions. However, their more fruitful reproductive ecology is what gives them an edge over the natives occupying a given territory.

Bark stripping by *S. niger* induces branch killing due to the degradation of their protective coating (Kenward, 1983). In general, branches are weakened from *S. niger* gnawing off the outer bark. As they break off, the plant is more susceptible to disease due to an accessible point of entry for pathogens. This weakens the tree, potentially leading to death of the plant altogether (Kenward, 1983).

Both *S. griseus* and *S. niger* are omnivores and share a similar diet. However, *S. griseus* has a more selective diet than the generalist diet of *S. niger* (Corona, 2019). Since *S. niger* eats a broader range of insects than *S. griseus*, it has a more substantial effect on this lower trophic level. Insects that originally were not consumed by tree squirrels may now be targeted by the invasive squirrel species (Corona, 2019).

F. Human Health Impact

We found no literature on the impact of *S. niger* on human health. However, as mentioned previously, they have been known to physically attack humans carrying food, which could potentially lead to necessary medical treatment. In addition, they carry a variety of different viral diseases such as, rabies, west nile, squirrel fibromatosis, California encephalitis, Western equine encephalitis, and St. Louis encephalitis (Leitheiser, 2013). However, we were unable to find any literature that documents the transmission of these diseases from *S. niger* to humans.

G. Economic Cost

Sciurus niger has a reputation for damaging crops, hindering agricultural output. Although the effects of these species on crops such as citrus, avocado, walnut, and almonds are evident (Salmon et al., 2006), no quantitative data has been collected through studies. Property damage is also a big concern for individuals living in cities heavily invaded by *S. niger*. They are especially destructive in groups of high densities. Some examples of damage caused by *S. niger* include: destroying gardens and nut trees in urban cities, tampering with electrical wires resulting in power outages or fires due to short-circuiting, and aggressively attacking individuals with food (Wolf & Roest, 1971; Flyger & Gates, 1982; Hamilton et al., 1989; Vu, 2007; Lee, 2009). Coating electrical wires with glass beads serves as a repellent and has been effective at reducing damage (Kenward, 1983). *Sciurus niger* have also caused damage to wooden objects, including buildings and telephone lines, due to their tendency to nibble on these materials. Consistent patterns of property damage, due to the gnawing behavior of *S. niger*, were observed on the University of California, Davis (UCD) campus. Items made of hard plastic material such as sprinkler heads, utility covers, outdoor grill handles, benches, picnic tables, and the dashboards of utility vehicles are especially prone to biting damage by *S. niger* (Krause, 2010). In the past, UCD has spent an excessive amount of money on repairing damage caused by *Spermophilus beecheyi*, a species of squirrel native to California. Considering that *S. niger* has become much more abundant on campus than *S. beecheyi* has ever been, the university will have to allocate a larger portion of their budget to the economic burdens caused by this invasive species (Krause, 2010).

H. Best Practices

Efforts to control the economic and ecological burdens inflicted by *S. niger* include exclusion, habitat modification, repellents, trapping, shooting, and recreational hunting (Salmon et al., 2006). These management strategies can be separated into two broad categories: Lethal and Non-Lethal Management. However, these methods of management are not always practical, effective, or socially acceptable in urban and suburban regions, where a majority of *S. niger* reside.

Lethal Management:

As long as the regulations for hunting established by California are carefully followed, *S. niger* is a game species that can be shot year-round in appropriate areas. Shooting these animals is also allowed when they damage property or disrupt crop yields. Relocating these species is illegal, because it could increase their chances of spreading to new regions. For this reason, lethal traps are highly favored over ones that allow the animal to survive upon their capture (Salmon et al., 2006). The use of these lethal approaches, although proven to be effective, is an area of controversy among individuals (Krause, 2010). Using poisons to control populations of *S. niger* is illegal because it does not specifically target this group alone. This method inflicts harm on the surrounding environment by poisoning nearby plants and animals (Salmon et al., 2006). Currently, no existing toxins have a high enough specificity to differentiate between organisms on a species level. However, the development of a toxin that specifically targets *S. niger*, may be a potential area of future research that can be conducted through biochemical assays.

Non-Lethal Management:

In landscaped settings, the presence of trees is often preferred due to their aesthetic appeal. However, cutting down trees as a method of habitat modification would be an excellent way to contain squirrel populations within these areas. This approach would specifically target *S. niger* because they are commonly found in urban cities, while the natives reside in more heavily vegetative environments. Nonetheless, there is a more general, overarching ecological issue with this approach. Trees carry out vital functions within our ecosystem, such as modulating levels of greenhouse gases, contributing to the water cycle through evapotranspiration, and providing other organisms with a home (Pachamama Alliance, 2019). Utilizing this approach would certainly aid in removal of these invasives, but at a high cost.

Use of contraceptives to sterilize these animals, preventing them from reproducing, is a new method of management being used more frequently. The UCD campus has employed a contraceptive called, GonaCon™, an immunocontraceptive vaccine, developed by researchers at the USDA National Wildlife Research Center (NWRC) (Miller et al., 2004). This is a popular approach to pest management because it prevents the need for any lethal actions, appealing to the individuals who find shooting or lethal traps to be socially unacceptable (Krause, 2010). This research center is developing many different types of contraceptives that can be used to decrease *S. niger* populations in urban regions (Killian et al., 2006).

In Britain, a similar dilemma involves the invasion of *Sciurus carolinensis* into regions where *Sciurus vulgaris* is native to. Some of their management methods include the removal of *S. carolinensis* by setting traps in nearby regions where only this invasive squirrel is found. In addition, they have also introduced *S. vulgaris* within a selected region so that the population density of the native squirrels can increase (Venning et al., 1997). These efforts can reduce the competition imposed by the invasive species by limiting their expansion, while encouraging the

native populations to flourish. Researchers have also implemented an approach referred to as "selective supplementary feeding." The Forest Commission in the United Kingdom has devised a supplementary food hopper that only the native squirrels can utilize, due to the selective nature of this device. This feeding assistance technique exploits the difference in weight between the two species of squirrels. *Sciurus vulgaris*, which weighs less than the pest, can successfully access the food available on the device, while the heavier species of squirrel falls through the weight sensitive "see-saw floor" (Pepper, 1993). This tactic can be employed in Los Angeles as well due to the discrepancy in weight between *S. griseus*, 15 ounces, and the heavier *S. niger*, 29 ounces on average. However, the extent to which natives benefit from this supplementation is unclear. Furthermore, supplementary feeding in general results in an increase in the incidence of disease transmission (Robb, 2008).

Category 3. Terrestrial Plants

Arundo donax (Giant Reed)

A. Life history

Arundo donax is an invasive grass common to riparian ecosystems (USDA, 2014). The species is found along streambanks, desert springs, flood plains, drainages, and irrigation waterways (USDA, 2014). It is a perennial rhizomatous grass with a root system that consists of tough, fibrous, lateral rhizomes, and deep roots (USDA, 2014). It primarily reproduces vegetatively, sprouting from disturbed stems or rhizomes buried up to 10 feet deep (USDA, 2014). Stem or root parts smaller than two and a half inches have the potential to resprout if a node is present (USDA, 2014). Seed viability is very low, and seedling establishment from germinated seed is rare (USDA, 2014). The plant flowers from June through November, depending on location, and the inflorescence is a dense, plume-like panicle that is one to two feet in length (USDA, 2014). One of the primary reasons that *A. donax* can spread so extensively in all riparian areas is because it is able to invade via clonal growth and dispersal (Herrera & Dudley, 2003). The clonal nature of the plant makes it well adapted for high disturbance dynamics of riparian systems, because fragmented stem nodes and rhizomes can take hold and generate new plant clones as floods break up clumps of *A. donax* (Bell, 1997). Therefore, the floods may work to the plant's advantage in terms of fitness and spread, as floods catalyze its spread along the river (Bell, 1997). Once established, *A. donax* can outcompete native riparian vegetation due to its incredible growth rate of up to five cm per day (Perdue, 1958).

a. Identification

Arundo donax is a bamboo-like grass with stems that grow over 20 feet tall (USDA, 2014). From far away, it looks like a corn plant. It is similar in appearance to *Phragmites australis*, but is much larger (USDA, 2014).



Figure 5-1: From left to right display of *Arundo donax* plant, stem/leaves, and flower. (Left and right photos by James H. Miller, USDA, 2014. Center photo by David J. Moorhead, USDA, 2014.)

B. Origin

Historically, *A. donax* was thought of as a species native to sub-tropical Eurasia, which encompasses the Mediterranean Basin, as there are descriptions of it in Spain and south-eastern France by Carl Linnaeus dating back to 1753 (Leriche et al., 2014). However, recent studies generated amplified fragment length polymorphism (AFLP) fingerprints of clones from the Mediterranean Basin that have revealed a surprising lack of genetic diversity in and around the area (Hardion et al., 2012). This indicates that *A. donax* is invasive to the Mediterranean region as well, likely placing its origin somewhere in Asia (Leriche et al., 2014). AFLP and inter-simple sequence repeat (ISSR) analysis of Asian and Mediterranean specimens supports the plant's monophyletic origin in Asia (Mariani et al., 2010). Other studies support this hypothesis as well, as they document lower cytotypes in Thailand (Larsen, 1963) and India (Christopher & Abraham, 1971) than in the Mediterranean (Pizzlongo, 1962). This higher ploidy level in Mediterranean populations may cause the non-fruited nature of these populations, by disrupting their meiotic processes (Leriche et al., 2014).

C. Current Global/ National Spread

Arundo donax has spread around the world (Bucci et al., 2013). It is believed that the species was initially introduced to North America from the Mediterranean region, although it has been subsequently introduced from many different places (Ahmad et al., 2008). *Arundo donax* has aggressively spread globally and nationally (Bucci et al., 2013). It is found globally and is considered invasive in many warm regions, including Oceania, Africa, sub-tropical Eurasia, and the Americas (Herrera & Dudley, 2003). In the United States, it is particularly invasive in the southern half of the country, proliferating aggressively in riparian habitats from California to Maryland (Ahmad et al., 2008).

D. Distribution in Los Angeles County

Arundo donax was intentionally introduced to California in the Los Angeles area in the 1820s as a method of erosion control in drainage canals and thatching roofs (Hoshovsky, 1987). It has since spread outside of containment and is now prevalent in many of Los Angeles's riparian watersheds (Giessow et al., 2011). The only large-scale mapping project of *A. donax* in California was done by Giessow et al. (2011) for the California Invasive Plant Council, and they were able to map it for all coastal watersheds from the Salinas River in Monterey County in the north to the Tijuana River in the south. In order to survey and map the region of interest, they divided it into functional hydrologic units (Giessow et al., 2011). The created map (Figure 6-2) demonstrates the extensive population distribution of *A. donax* in the study area, including Los Angeles County, and how it has invaded vast areas of the Los Angeles watershed (Giessow et al., 2011). In these mapping efforts, it was determined that there were 132.8 total acres of *A. donax* throughout the Los Angeles hydrologic unit (Giessow et al., 2011). The map demonstrates the extensive population distribution of *A. donax* in Los Angeles County and how it has invaded vast areas of the Los Angeles watershed (Giessow et al., 2011). Another map (Figure 6-3), retrieved from iNaturalist, displays user *A. donax* sightings in Los Angeles County, and also illustrates *A. donax*'s extensive spread (iNaturalist, 2019).

Arundo donax extensively changes the ecological and successional processes in Southern California riparian systems, eventually shifting most of these habitats towards homogeneous environments of this invasive grass (Bell, 1997). Understanding this is of utmost importance, as Southern California riparian habitats are already endangered (Faber et al., 1989).

A. donax forms large clonal root masses, which can cover several acres, to the detriment of native vegetation (Bell, 1997). Additionally, *A. donax* is extremely flammable and contributes to more complete burning of native vegetation during fires (Bell, 1997). At first, this might seem to be an evolutionary disadvantage; however, its rhizomes respond quickly after fire, re-growing and outcompeting native species that had previously been present (Bell, 1997). Thus, by burning frequently and more completely than native vegetation, it can create a barren habitat that it can quickly gain control over to outcompete native species (Bell, 1997).

Additionally, there is evidence that this species is not a significant source of food or habitat for native species (Bell, 1997). *A. donax* contains various noxious chemicals, such as silica, in its stems and leaves (Jackson & Nunez, 1964). This, along with cardiac glycosides, curare-mimicking indoles (Ghosal et al., 1972), and alkaloids, provide protection from many native insects and grazers (Miles et al., 1993). This leaves regions dominated by *A. donax* largely devoid of other wildlife.

Aside from altering the abundance of other organisms in riparian ecosystems, *A. donax* also alters the physical habitat structure. The extremely thick root masses it generates, which can be over a meter thick and fortify stream banks, can change flow regimes (Zahran & Willis, 1992). The plant is also devoid of the canopy structure that is necessary to shade river water (Chadwick & Associates 1992). This results in warmer water temperatures in rivers where it is prominent, which in turn lowers oxygen concentration and ultimately aquatic animal diversity (Dunne & Leopold 1978). The reduced canopy may also increase pH in shallow portions of rivers, degrading water quality for organisms downstream (Chadwick & Associates 1992).

In summary, *A. donax* can invade rampantly due to a combination of rapid clonal reproduction (Bell, 1997), prolific growth rate (Perdue, 1958), and high degrees of environmental tolerance and adaptation (Quinn & Holt, 2007). Once established in a new riparian habitat, it significantly reduces biodiversity and alters the physical characteristics of the habitat (Bell, 1997).

F. Human Health Impact

In terms of impact on human health by *A. donax*, there is little literature documenting any negative impacts. In fact, it has been used for hundreds of years as a medicinal plant and has modern pharmacological promise (Al-snafi, 2015).

G. Economic Cost

The control of *A. donax* is of vital importance not only because the plant negatively impacts native riparian ecosystems, but also because its dispersal results in high economic costs (Giessow et al., 2011). The species generates these costs primarily in two ways. First, it significantly increases the spread and intensity of wildfires, driving up costs of fire containment (Giessow et al., 2011). It also generates an economic burden in several tangential ways, including flood damage, water use, and sediment trapping (Giessow et al., 2011). These dangerous and costly impacts of wildfires, in conjunction with negative impacts on ecosystem health, have generated large-scale control and elimination efforts, which are also economically costly.

Annual wildfires in Southern California have been documented as costly financially, and in 2007, the wildfires generated an estimated cost of \$44.5 million in Los Angeles County alone (Keeley et al., 2009). There are two primary ways in which *A. donax* impacts wildfires (Giessow et al. 2011). The first is generating them directly, and the second is changing the way existing fires behave, exacerbating their spread (Giessow et al., 2011). In conjunction, these two aspects greatly impact wildfires and can greatly increase economic cost of wildfires (Giessow et al., 2011).

The first impact that *A. donax* has on fires is that it causes fires to burn at higher temperatures and more completely in riparian areas (Giessow et al., 2011). Often, large wildland fires will burn riparian vegetation in the presence or absence of *A. donax* (Giessow et al., 2011). However, there are frequently areas within riparian zones containing native vegetation that do not burn as completely, as native vegetation generally contributes higher water concentration and poorer ventilation (Giessow et al., 2011). *Arundo donax* tends to grow densely, creating significantly more biomass to act as fuel for the fire (Spencer et al., 2006; Giessow et al., 2011). Additionally, the plant maintains a mostly vertical physical structure, increasing ventilation in comparison to other native vegetation, creating a hotter and more complete burning of vegetation (Giessow et al., 2011). This hotter and more complete burning likely generates the second impact (Giessow et al., 2011).

The second impact that *A. donax* has on wildfires is that it seems to bridge fires across riparian habitats, linking upland vegetation that might otherwise be separated by less flammable native vegetation (Giessow et al., 2011). The *A. donax* lining the rivers creates a fire corridor because the fire has large amounts of biofuel lining the river beds, increasing transfer to other areas that are not yet burning (Giessow et al., 2011). Together, these two impacts have induced fire spread on a devastating scale (Giessow et al., 2011), in turn generating massive economic costs to combat these fires.

In 2003, the Verdale fire began as a smaller fire that burned 8,784 acres, but upon reaching the Santa Clara River, *A. donax* ignited and began burning at extremely high temperatures (Giessow et al., 2011). In turn, the fire crossed the river and burned an additional 107,560 acres in Simi Valley (Giessow et al., 2011). Cal Fire estimates that the Simi Valley fire generated around \$10 million in costs (Simi Fire General Information, 2003). Together, these studies imply that *A. donax* may have single-handedly increased the cost of these fires by millions of dollars, and this does not include the resulting economic impact on families who were displaced as a result. Similar fire freeway complexes, in which *A. donax* transferred fires to new areas, were observed in the 2007 San Dieguito Watershed fire (Giessow et al., 2011). The fire freeway complexes are narrow pathways formed by *A. donax* that provide a direct route for transfer of fires between habitats that would otherwise be separated if populated by native vegetation (Giessow et al., 2011). In short, it seems that *A. donax* greatly exacerbates the conditions and spread of California wildfires (Giessow et al., 2011), which in turn generates massive economic burden, and may continue to do so if it continues to dominate riparian ecosystems.

The negative impacts that *A. donax* has on the ecosystem and wildfires has garnered it large amounts of attention for management and control, but this management and control comes at a steep economic cost (Giessow et al., 2011). A full cost-to-benefit analysis demonstrates that as of 2011, over \$70 million had been spent attempting to control *A. donax* within the study area from the Salinas River in Monterey County in the north to the Tijuana River in the south over a

15-year period (Giessow et al., 2011). The study estimated a management cost of approximately \$25,000 per acre of *A. donax* (Giessow et al., 2011).

Additionally, complete elimination of *A. donax* in the study regions would generate estimated savings of \$49.6 million, \$2.5 million, and \$17.3 million over a 10-year period by reducing water usage, sediment trapping, and flood damages, respectively, if started in 2011 (Giessow et al., 2011).

In conclusion, *A. donax* results in millions of dollars in economic cost due to several factors (Giessow et al., 2011). This makes controlling it and preventing its spread of the utmost importance, not only for ecosystem and environmental reasons, but also for reasons of human interest.

H. Best Practices

The eradication and control of *A. donax* is a top priority in Southern California because of its extreme impact on the riparian ecosystem and habitat (Bell, 1997). Eradication is ideal, but to date, eradication has proven to be difficult in California (Giessow et al., 2011). Often times, complete elimination is impossible (USDA, 2014). In these circumstances, preventative measures are best (USDA, 2014). Whether utilizing eradication or preventative measures, proper top-down control and strategic habitat prioritization are vital for success (USDA, 2014).

Top Down Control and Strategic Habitat Prioritization

Two key aspects to consider when determining strategies for control of *A. donax* are where in the watershed to begin and which watersheds to prioritize. Due to *A. donax*'s vegetative reproduction, most published studies recommend a top-down approach when eradicating the species (Giessow et al., 2011; Quinn & Holt, 2007). This entails starting the eradication process at the top of the watershed and moving downstream as eradication is completed (Quinn & Holt, 2007). Additionally, rhizomes sprout regardless of initial size or environmental condition, so complete removal of all living rhizome pieces is necessary before moving further down the watershed (Decruyenaere & Holt, 2001; Quinn, 2006). Despite most literature supporting this model, a study of the Tijuana River Valley challenges this notion, at least in this specific area. The study concluded that *A. donax* was spreading laterally within the habitat, rather than from upstream to downstream (Boland, 2006). While this study yields conclusive results, management suggestions and strategies in Southern California remain anchored in the theory of top-down eradication (Giessow et al., 2011).

Selecting which watersheds are highest priority is also of great importance. One study recommends prioritizing removal of *A. donax* from riparian habitats that are adjacent to fire-prone shrublands that have yet to be invaded because it found wildfires promote invasion of riparian ecosystems by *A. donax* (Coffman et al., 2010). Other watersheds that should be prioritized for funding for removal are those that have already implemented *A. donax* management but are experiencing regrowth (Giessow et al., 2011). This should be done to protect existing investment and those that have low levels of invasion, as it is more cost efficient to control the plant before it proliferates extensively (Giessow et al., 2011).

Re-treatment in areas that have previously been treated and are experiencing regrowth is recommended as the highest priority because such a large monetary investment has already been made in these areas, and they have already proven to have the capacity to support large amounts of *A. donax* (Giessow et al., 2011).

Implementing effective overarching strategies for removal is important for generating successful results with efficient allocation of funding. However, the specific techniques used to do the actual removal are equally important. In some cases, eradication may not be feasible, so preventing spread and managing levels of invasion are the best strategy (USDA, 2014). In other cases, eradication is feasible, and there are two main methods to eradicate *A. donax* (USDA, 2014). The two primary methods of eradication management used in Southern California are mechanical and chemical, with each having benefits and drawbacks (USDA, 2014). Biological control is also an option for certain circumstances.

Prevention of Spread Methods

When complete elimination is not feasible, the primary objective for managing *A. donax* becomes suppressing existing infestations and limiting its spread through maintenance of healthy native plant communities (USDA, 2014). The United States Department of Agriculture has recommended methods of control under these circumstances. These two methods are called cut-regrow-spray and mulch-excavate-spray (USDA, 2014).

The cut-regrow-spray method is best for areas where *A. donax* is mature and growing in dense formations with little space between canes (USDA, 2014). This method involves cutting the stalks early in the growth season, removing the debris, and then foliarly applying 3% to 5% glyphosate solution when the plants regrow to about three feet in height (USDA, 2019). One of the primary benefits of this plan is that it reduces use of herbicides, and it should be strongly considered when working in sensitive habitats that contain endangered species (USDA, 2014). The area must be monitored for resprouting plants in the next growing season (USDA, 2014).

The mulch-excavate-spray method is best for treating a high density stand of *A. donax*. This method involves using a hammer-flail mower attached to a tractor or rotary brush cutter to mulch the species in October and November (USDA, 2014). This method also requires herbicidal treatment, which is the same as the method outlined for the cut-regrow-spray method. The treated area must be monitored for resprouting plants for three to five years following the treatment (USDA, 2014).

Biological Control Methods

Currently, the only biological control method that is known to be effective is grazing, but animals generally find *A. donax* unpalatable and will only graze young green shoots during the dry season (USDA, 2014). Angora or Spanish goats can be used to suppress resprouts after other treatments have been made, but they should not be used in areas that have been treated with chemical herbicides, such as glyphosate (USDA, 2014).

Mechanical vs Chemical Control Methods Environmental and Health Trade-offs

Although *A. donax* can be controlled using mechanical and chemical methods, both of these have unintended consequences on the environment (USDA, 2014).

The primary benefit of utilizing mechanical methods is that there will be no glyphosate added into the environment, which is harmful to many native species and can take years to fully dissipate from the environment (USDA, 2014). Additionally, glyphosate has recently been shown to be more harmful to human health than originally thought. For example, it has been shown to be genotoxic, causing damage to DNA in human-derived buccal epithelial cells at concentrations diluted 450-fold from concentrations used for spraying agriculture (Koller et al., 2012). The same study suggests that DNA damage may be caused simply by inhaling glyphosate

(Koller et al., 2012). Thus, caution is advised when implementing chemical control methods. Also, a different study found that glyphosate may act as an endocrine disruptor by altering estrogen receptors, ultimately causing breast cancer (Thongparkaisang et al., 2013). Because glyphosate is genotoxic and exhibits carcinogenic properties, it should be used with caution and only with proper discernment. This is especially true for use on *A. donax* because the species grows primarily in watersheds in Southern California, so any glyphosate sprayed for management will end up in the watershed to some extent (Giessow et al., 2011).

While mechanical control avoids the chemical risks associated with glyphosate application, it can cause major soil disturbance and interfere with native plant establishment (USDA, 2014). Sometimes, this results in increased invasions from other noxious weeds on cleared sites that will require additional management in the future (USDA, 2014). Thus, if using mechanical removal methods, it is critical to replant the cleared areas with native vegetation to minimize chance of *A. donax* regrowth (USDA, 2014). This can make mechanical removal time consuming and costly financially (USDA, 2014). Therefore, neither chemical nor mechanical removal is perfect and will likely result in some peripheral damage to the ecosystem (USDA, 2014).

Manual/Mechanical Control Methods

Manual control options for *A. donax* are limited and not generally recommended (USDA, 2014). Hand removal is very difficult, but digging can be used to target individual plants (usually less than six feet tall) if the removal effort is small scale (USDA, 2014). To help with handling, it can be helpful to first cut the canopy near the surface using a chainsaw, machete, or pruning shears before pulling up the remaining portions of reed stems, rhizomes, and roots (USDA, 2014). It is critical that the entire root mass and associated rhizomes are entirely removed from the soil (USDA, 2014). To prevent reshooting, uprooted material should be removed or burned onsite, and the area should be replanted with native vegetation (USDA, 2014).

Mechanical methods for removal are sometimes useful on their own, but they are generally most effective when used in conjunction with chemical control methods and followed with planting or seeding of desired native species to prevent regrowth (USDA, 2014). There are two types of mechanical methods used for removal (USDA, 2014). The first of these is called excavating, and it involves using a backhoe and grapple to remove small, dense stands of *A. donax* (USDA, 2014). Excavating is not recommended in the streambed or edge because root material may be washed downstream (USDA, 2014). The second mechanical method of removal is mulching, and it can be used on accessible sites that have less than 30% slope and do not have sensitive terrain (USDA, 2014). This is done with a hammer-flail mower attached to a tractor to cut top growth in the late fall or winter. It is followed up with herbicide spraying the next season and again in summer of the third year (USDA, 2014).

Chemical Control Methods

The most important aspect of eradicating *A. donax* is killing the root mass (Bell, 1997). The most well-established methods of *A. donax* removal involve the use of herbicides, such as glyphosate (Bell, 1997). There are many different strategies involving herbicidal treatment, and their effectiveness depends on the amount of biomass present, size of the stand, the season, and terrain (Bell, 1997). It is important to limit the number of treatments in order to minimize labor

costs, physical impacts on habitats by site visits, and chemical impacts on sensitive habitats (Spencer et al., 2008). Highly efficient, single late season applications are the best way to do so (Spencer et al., 2008).

Review of the literature indicates that the most effective way to chemically kill the species is with a single late season application with foliar application of 3% or 5% glyphosate for plants less than six feet in height (Bell, 1997; Spencer et al., 2008). Late season spans mid-August to early November, which is the period in which *A. donax* actively transports nutrients to the root mass (Bell, 1997). By timing treatment correctly, the glyphosate will be transported to the root mass more efficiently, increasing success rate (Bell, 1997). This foliar application is done with hand-held, pump-up, or backpack sprayers (USDA, 2014). The entire canopy must be wet thoroughly without allowing dripping to occur (USDA, 2014). It may be best to cover native vegetation with a tarp before applying the herbicide, and spraying under high winds or before anticipated rainfall is not advisable, as these conditions reduce effectiveness of foliar application methods (USDA, 2014).

Another possible treatment chemical treatment method that reduces the glyphosate use is called the individual plant treatment (IPT) cut stump treatment (USDA, 2014). This method involves hand cutting stems two to four inches above the ground and then applying a concentrated glyphosate solution (50% to 75%) to the stump surface within one to three minutes of cutting with a paintbrush or hand-held spray bottle (USDA, 2014). The lower concentration is used in spray bottles, while the higher concentration should be used when directly applying glyphosate to the stumps with a paintbrush (USDA, 2014). This is most effective when done in the late fall and should not be done when the species is dormant (USDA, 2014). A nonionic surfactant and blue indicator dye should be added to the spray mixture as well (USDA, 2014). Cut debris must be disposed of properly, as outlined in table 6-1 (USDA, 2014). This method can be difficult to implement in large scale removal efforts and the short window of time required between cutting and chemical application can reduce success rates (USDA, 2014).

For regions with very dense populations of *A. donax* that are difficult to reach by foot, helicopter spraying of 3% to 5% glyphosate may be the only feasible method of eradication (USDA, 2014). Helicopter application is superior to application from a plane, because it allows for more precise spraying (USDA, 2014). However, eradication is often unlikely in areas with dense infestations of mature *A. donax*, and given the numerous detrimental health and environmental impacts that glyphosate has, this method should only be used in circumstances where eradication is likely. If eradication is not feasible, preventative methods are highly recommended to minimize use of herbicides.

Post-removal Debris Management

The USDA has created a table (Table 5-1) of debris management recommendations based on the removal techniques used, which is vital in preventing regrowth (USDA, 2014). The primary debris management options are as follows: leave in place, burn onsite, mulching, chipping, composting, and removing debris (USDA, 2014). Leave in place is best used after herbicidal spray (USDA, 2014). By leaving the plants in place, it allows the chemicals to be taken up into the rhizome and root mass (USDA, 2014). This is one of the primary benefits of using glyphosate-based management plans, as it reduces post-removal labor and costs by eliminating removal altogether (USDA, 2014). Burning the stems and rhizomes ensures that they are killed and prevents regrowth and can be used following any removal method, but in the arid Southern California climate, this may not be ideal due to wildfire risk (USDA, 2014).

Mulching, chipping, and composting are best used following cut and paint or cut and spray techniques, and it is best to move waste piles away from the site afterwards (USDA, 2014). Removing debris is usually used following manual removal methods, but can be ineffective because even one missed piece of rhizome or stem can result in regrowth (USDA, 2014). Following removal and debris management, planting native species, such as *Salix sitchensis* (California Willow) is crucial to ensure that *A. donax* does not resprout or invade again (USDA, 2014).

Debris Management Option	Associated Control Method	Rationale/Recommendations	Special Considerations
Leave in place	Systemic herbicide spray; mulch-spray.	Cutting or removing sprayed plants before the herbicide has fully impacted the rhizome and roots may result in resprouting.	In some situations, sprayed plants left in place can create a fire hazard or impede flood control.
Burn onsite	All control methods	Broadcast burning before or after other planned mechanical or chemical treatments reduces standing biomass. Burning piled debris prevents potential resprouting.	Obtain required permits and alert local fire departments about activities. An air quality management district may have restrictions such as drying time before burn.
Mulching, chipping, or composting onsite	Use in combination with other methods such as cutting and later spraying.	Resprouting from debris is unlikely as long as plant parts are kept well away from wet situations; best used in remote areas.	Locate debris piles away from flowing water to prevent redistribution of plant parts. Debris is difficult to chip or mulch.
Remove debris	Manual methods, such as cut only or mechanical methods.	Plant parts will no longer be onsite to resprout; use choke-chain or rope to bundle debris or pile debris on a tarp to haul.	Labor intensive and finding a disposal company may be difficult because debris is hard to transport.

Table 5-1: Post-removal debris management practices of *A. donax* depending on different circumstances (Figure from USDA, 2014)

Overall Recommendation

In summary, studies indicate that the best, most environmentally-friendly, and funding efficient eradication practices in Southern California begin with a top-down approach (Giessow et al., 2011; Quinn & Holt, 2007). Additionally, it is critical to prioritize areas that have previously implemented watershed-based management or have yet to be invaded and are adjacent to areas prone to wildfires (Giessow et al., 2011; Coffman et al., 2010). When stands are small and less than six feet in height, a single late season foliar application of 3% to 5% glyphosate may be the most cost effective and efficient eradication method (Bell, 1997; Spencer et al., 2008). However, given the detrimental environmental and health impacts that glyphosate can have, methods that reduce herbicide usage should be heavily considered (USDA, 2014). The most effective of these methods include mulching, excavating, and cut stump treatment (USDA, 2014). In habitats with dense and mature stands, eradication may be impossible, but limiting its spread and managing existing populations is crucial to preserving what is left of the Southern California riparian habitat (Bell, 1997). If eradication is feasible, foliar helicopter application of 3% to 5% glyphosate solutions may be the only option, but eradication will usually not be possible (USDA, 2014). In these circumstances, focusing on managing spread with cut-regrow-spray and mulch-excavate-spray methods are highly recommended to suppress the infestation and limit its spread to new habitats (USDA, 2014). Following strategic removal or prevention, debris must be dealt with properly, and techniques vary depending on the type of removal or prevention techniques used (USDA, 2014).

Management of High Priority Invasive Species (Comprehensive Summary)

A. Short introduction

Invasive species have tremendous ecological, economic, and even human health impacts. The negative impacts of invasive species on ecosystem health extend to a multitude of ecosystem goods, such as fishery and agricultural products, and services, such as clean drinking water and climate stabilization. They are especially prevalent and harmful in urban centers like Los Angeles County. Thus, we created a comprehensive literature review on 11 high priority invasive species to compile the most effective management plans and recommendations best suited to target each species.

B. Methods

We selected invasive species based on several criteria, including current distribution within the Los Angeles region, relative threat to native species, and their prioritization by the National Oceanic and Atmospheric Association (NOAA). Thus, we conducted a literature review on the following invasive species: algae (*Sargassum horneri*), crayfish (astacoidea superfamily), giant reed (*Arundo donax*), fox squirrel (*Sciurus niger*), and the European starling (*Sturnus vulgaris*). To conduct our searches, we used several databases, such as Google Scholar, Web of Science, and UCLA Library Article Plus. We also utilized management recommendations from public and private agencies, such as the USDA National Wildlife Research Center, and the USGS Biological Resources Division. Additionally, we created statistics on existing management plans that are currently being implemented by cities within the Los Angeles County. We did this by contacting cities via emails that were directed towards parks and recreation departments, as well as by conducting internet searches of city websites to determine invasive plan accessibility to the public.

C. Findings

- a. Los Angeles County city statistics based on public accessibility of resources (whether or not they have an invasive species management plan in action)
 - i. 55.7% (49/88) of cities within LA county mention invasive species on their website.
 - ii. 20.5% (18/88) of cities within LA county have invasive species specific management plans in place and accessible online.

Invasive Species Management Plans in Los Angeles County by City

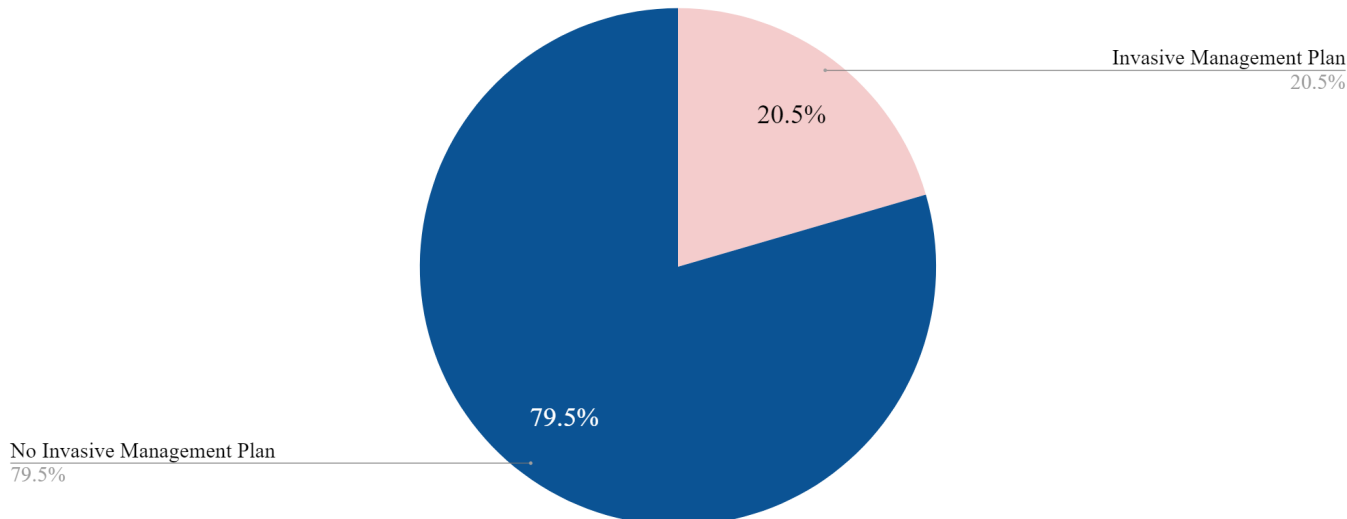


Figure 6: Percentage of cities within Los Angeles County that do or do not currently have a publicly accessible invasive species management plan.

b. Aquatic Species

i. Life history

1. The life history of these aquatic species contributes heavily to their invasiveness. For example, mature individuals of macroalgae *Sargassum horneri* possess air bladders, which allows detached individuals to float to new regions, possess both male and female gametes and therefore a single individual can create an entire new population, and contain polyphenols, a toxin that deters grazing by herbivores thus leaving them free of predation.
2. Freshwater crayfish have rapid growth rates and high fecundity, as well as disease resistance. This species is very aggressive allowing it to outcompete native species.
3. The zebra mussel feeds by filtering the water to collect phytoplankton while clinging onto the substrate. They are able to stay alive for several days outside of water and may colonize new regions by clinging onto the underside of boats moving to a different location. The zebra mussel has three life stages; larval, juvenile and adult. The larval stages live freely in the water column, allowing them to be easily transported to new ecosystems via currents.
4. The New Zealand mudsnail (*Potamopyrgus antipodarum*) is a nocturnal grazer that feeds on plant and animal detritus, algae, and diatoms. Invasive populations are capable of asexual reproduction,

and the females are born with developing embryos inside them. Thus, there are genetic clones in every population, and they primarily reproduce clonally through parthenogenesis, bearing live young. They can readily attach to recreationalist equipment, such as waders, boots, buckets, and any other item that can be emerged in water. The species survives for long periods of time on this equipment and are often transferred to new bodies of water when the equipment is used next.

ii. Ecological Impact

1. Because of the nested architecture of trophic interactions within aquatic system ecology, the impact of invasive species is not isolated, but rather proliferates through higher trophic levels as well. For example, invasion of *Sargassum horneri* often leads to a loss of giant kelp, an ecosystem engineer that provides vital habitat and resources for marine life, as well as a multitude of ecosystem services such as storm wave protection and absorption of excess nutrients from surface water runoff. As such, this macroalgae leads to a substantial decrease in biodiversity wherever it invades.
2. New Zealand mudsnail forms large and dense populations, because they reproduce at such an incredible rate. Because they form such immense population sizes, the New Zealand mudsnail can consume as much as 95% of diatom, attached periphyton, and detritus that are the native aquatic invertebrates' primary food sources. This causes a food shortage.
3. The crayfish threatens naive amphibians which can alter the natural balance of the ecosystem and the community structure.

iii. Economic Impact

1. New Zealand mudsnail and the zebra mussel clog water pipes and infiltrate water systems, which can result in costly damage through the process of biofouling. They also can negatively impact tourism. The zebra mussel does this by creating foul smell when decaying on the beach, while the New Zealand mudsnail negatively impacts recreational fisheries.
2. The crayfish causes economic costs from the ecological damage in agriculture, forestry and fishery sectors. The crayfish damages drainage systems because of its burrowing activities. The crayfish can also be problematic for fisheries by damaging fishnets and spoiling valuable fish being caught.

iv. Management

1. The underwater habitats severely limit management and removal options. Removal is very difficult, because it requires large amounts of equipment and resources to implement; the release of gametes in the water column is not possible to contain.
2. As such, physical removal as a method of control is only recommended early upon introduction of the invasive species to a new area. Once they become established, removal and eradication is rarely feasible, and resources should be shifted towards implementing preventative measures aimed at reducing further spread.
3. Physical removal: When the species are found in small bodies of water, physical removal is possible through draining infested areas in summer months or altering water temperature.
4. Preventative measures should target the main mechanisms of transfer between habitats. Items that facilitate transfer, including commercial and recreational boats, waders, boots, buckets, fishing gear, and any other item that is submerged in water should be thoroughly inspected and decontaminated. Prohibiting transportation of live crayfish would help prevent their spread.

c. Terrestrial plants

i. Life history

1. Terrestrial plants have rampantly invaded many areas in Los Angeles County. Differing life history traits make them better suited to invade unique habitats. For example, the giant reed effectively invades riparian habitats, because it invades via clonal growth and dispersal, making it well adapted for high disturbance dynamics of riparian systems. As floods break up clumps of the plant, fragmented stem nodes and rhizomes can generate new plant clones. In contrast, pampas grass can reproduce sexually and through vegetative cuttings, and is better suited for coastal Mediterranean habitats. On the other hand, black mustard only reproduces sexually with seeds. Seeds that are deeply buried within the soil can survive for decades and still successfully germinate, and most commonly found in coastal areas, often associated with sage shrub. As for fountain grass, its adaptability and ability to adjust its physiology allows it survive and thrive in habitats with a wide range of environmental conditions. Once it becomes established, the prolific production of long-lived seeds further impedes the control of fountain grass.

ii. Ecological Impact

1. All four invasive plant species thrive after wildfires. They often quickly colonize habitats freshly burned by fires, outcompeting native species, which results in an overall decrease in biodiversity.
2. The giant reed, fountain grass, black mustard, and pampas grass all grow extremely quickly, often overwhelming surrounding native vegetation. In particular, the giant reed has a tendency to outcompete all other vegetation, creating a homogenous “giant reed” habitat. Black mustard also outcompetes native species, due to extremely fast germination times, seed durability, and allelopathic effects.

iii. Economic Impact

1. An economic impact that these invasive plant species contribute to is the exacerbation and spread of wildfires. The giant reed, pampas grass, black mustard, and fountain grass all ignite easily and burn readily, increasing the intensity and frequency of wildfires. For example, the giant reed transferred the Verdale fire, which burned over 8,000 acres, to Simi Valley, igniting the Simi Valley fire, which burned over 100,000 acres and cost over \$10 million in damages and to extinguish.

iv. Management

1. A critical first step of any management effort is to decide on priority areas where resources should be concentrated. Prioritization could go towards areas that have already been treated and heavily invested in, new small or sporadic infestations, or areas that are prone to fires or adjacent to fire prone areas.
2. Physical removal as a method of management is feasible for smaller invasive plants that are more accessible, it is possible to cut the top of the plant and then remove the root. However, dense growth impedes such efforts due to inability of the machinery to access such areas as well as the high cost of labor required.
3. Chemical methods of management, mainly via glyphosates, have been widely employed, however recent research suggests possible carcinogenic effects of such herbicides. A cost-benefit analysis that takes into consideration the newly revealed health implications of glyphosates is critical in order to assess when it is appropriate to use such methods.
4. Post-removal management is another aspect that must be addressed. Options include mulching or burning the debris to

prevent seedling regrowth, shading the cleared area or planting native species to prevent recolonization by an invasive.

5. Regardless of the method employed, the key to successful invasive species control efforts is a long-term commitment to management, including annual monitoring and performing follow up treatment(s) upon regrowth and newly emerged seedlings.

d. Terrestrial animals

i. Life history

1. Los Angeles County often attracts invasive terrestrial animals and insects that can thrive in urban and agricultural ecosystems. For example, the European starling is an invasive bird that can nest in trees, building cavities, and streetlights. The fox squirrel is capable of outcompeting the native western gray squirrel due to its more fruitful reproductive ecology. The polyphagous shot hole borer (PSHB) is an invasive insect that carries a fungus, known to kill trees. PSHB burrows into trees for habitat, and in doing so, spreads its fungus.

ii. Ecological impact

1. PSHB affects native California tree and plant species, such as the sycamore, coast live oak, arroyo, and black willows. As a result, animal species that rely on the affected native species can lose their source of food and habitat. The European starling and the fox squirrel outcompete native species, such as the western grey squirrel and the western screech owl. Thus, invasive species create a disruption in ecosystem trophic hierarchies.

iii. Economic impact

1. Terrestrial invasive species can damage agricultural cropland and city infrastructure. Avian species like the European starling cause damage to cherry and wine grapes in California. Specifically, in cherry croplands, European starlings can cause up to \$2,000 worth of damage per hectare of land. Mammal species like the fox squirrel damage citrus, avocado, walnut, and almond crops. In addition, terrestrial invasive species often invade urban areas and can damage electrical wiring. For example, the fox squirrel has been known to damage telephone lines, sprinkler heads, and wooden benches. In California, it was estimated that out of a total of 70.8 million urban trees, 23.2 million of them are susceptible to PSHB. In Southern California, PSHB may damage avocado croplands, resulting in economic drawbacks for farmers.

iv. Management

1. Species like the European starling and the fox squirrel are present in high densities within Los Angeles County. Consequently, complete eradication is unlikely. Should mostly use non-lethal management methods for the European starling, while both lethal and non-lethal methods are effective for the fox squirrel.
2. It is better to implement non-lethal management methods for the European starling to avoid chemical tradeoffs. However, lethal traps and hunting, along with the use of contraceptives, cause negligible harm to the environment.
3. Non-lethal management involves habitat modification, such as reducing access to common nesting spots for invasive birds and preventing the entry of fox squirrels into regions the natives occupy. Invasive birds can be removed if frightening repellents are used, such as recorded bird alarm calls and animated scarecrows. Immunocontraceptives can be used to sterilize fox squirrels, taking away their major reproductive advantage.
4. Lethal management: Both the starling and the fox squirrel can be trapped and ethically euthanized. The two species can be hunted as well, depending on local and state gun laws. Hunting these species may require depredation permits.
5. There are some pesticides that can kill avian species, such as Starlicide. However, the use of chemicals should be avoided due to damage that they can cause in the ecosystem. Use of poisons for killing fox squirrels is illegal in the U.S for this reason.

D. Data limitations and future directions

1. The statistics regarding the number of cities that had invasive species management plans was limited due to some city paperwork not being digitized and published online. A lot of official documents are paper based, and the paper trail is often hard to access by the public or researchers. Once we found a point of contact, via email, we experienced an inconsistent response rate. Therefore, our statistical value is focused on the management plans accessible to the public. This might underestimate the management plans accessible for the relevant city managers.
2. Our systematic selection of scientific papers, and relevant websites compiled together for the literature review, could have been more consistent by creating more extensive guidelines assigned to each specific management method.
3. The invasive species that we chose are widespread, and thus, research into management guidelines of these species were often not specific to Los Angeles County. This may

create a discrepancy in the application of our selected management guidelines. This is likely because research papers that we chose regarding management may have been conducted under varying: intensity of invasion, local climate, monetary budget, soil conditions, and other abiotic and biotic factors. Therefore, some of the recommendations might not be completely translational if they are taken from studies conducted in areas other than Los Angeles County.

Management of an Invasive Algae: *Sargassum horneri* (“devil weed”)

Management guidelines for *Sargassum horneri* are relevant for managers of coastal cities, especially in cities with harbors. Monitoring for *S. horneri* in non-invaded areas is important for early detection and intervention. However, in areas where *S. horneri* populations are already established, eradication is unfeasible in most cases. In such cases, the most efficient methods of controlling the spread of *S. horneri* include educating harbor users on how to identify *S. horneri*, as well as implementing and enforcing preventative measures to stop the further spread of this species.

Detection methods

Differentiating between native *Sargassum muticum* and invasive *Sargassum horneri*:

Sargassum muticum has dense, compact branches, whereas *S. horneri* has bushy, fluffy branches. *Sargassum muticum* can have several stipes per holdfast, whereas *S. horneri* has one stipe per holdfast.

Sargassum muticum recruits have thin branches radiating from stipes, whereas *S. horneri* recruits have branches with symmetrical and flat shape with notched margins.

Mature *S. muticum* have oblong conceptacles, whereas mature *S. horneri* have reproductive receptacles that exude eggs when fertile.

Removal efforts

- Should target areas where *S. horneri* was very recently introduced, or old marine protected areas where native kelp populations are strongly established.
- Should be performed during the fall, to target *S. horneri* populations before they reach their reproductive stage.
- Should not be performed during periods when the water is relatively warm (i.e: during el nino season) because kelp population would not be able to colonize the cleared area under such conditions.
- Do not necessarily need to kill all living tissue, severing the plant right above the holdfast is enough to kill it.

Preventative measures

Important to implement in areas where *S. horneri* is already established. Especially relevant at harbors. Main vectors are boats and divers: *S. horneri* can spread via ballast water or by attachment to the hull or anchor of a boat. It can also spread through the gear of scuba divers, or by accidental removal and release of individual plants which can then drift and colonize other areas.

Education:

- Educating harbor users on how to identify *S. horneri* and to differentiate it from native algae.
- Educating harbor users on how accidental spread of *S. horneri* usually occurs.

Guidelines for boaters:

- Cleaning hull before leaving the harbor
- Removing fragments from anchor, lines and deck before leaving to a new location

Guidelines for divers:

- Dive in uninfested areas first before diving in an area where *S. horneri* is present if you plan on diving in both locations.

- Remove seaweed fragments from yourself and from your gear.

Management of Invasive Freshwater Crayfish: *Procambarus clarkii*

Crayfish are a prevalent invasive species in Los Angeles County. Management guidelines for crayfish are relevant for managers dealing with lakes, ponds, streams, canals, swamps and marshes. The aggressive species impacts the ecological balance of native riparian ecosystems in Los Angeles and affects both agriculture and fishing industries. Management options for this species include physical removal, prevention strategies, and natural or existing barriers.

Physical Removal

- Traps such as fyke nets, seine nets, line fishing and electro fishing.
- Bait, such as roach, bream or bleak can increase the number of crayfish trapped.
- Higher capture rates have been seen in shallow streams.
- Large flow events can remove crayfish from an area. This can be timed with physical removal for more effective elimination.

Preventing the Spread

- Prohibit the transportation of live crayfish.
- Encourage public education and awareness regarding the negative ecological, economic and health impacts of crayfish.
- Prohibit the use of crayfish as bait for fishing, as food, as pets and in aquaculture.

Barriers

Barriers have been shown to effectively reduce crayfish numbers upstream. However, barriers can cause damage to native aquatic species. Examples of barriers include;

- Channeling and obstructions of flow ways.
- Waterfalls, culverts and pipes that prevent the crayfish moving upstream.
- Drainage of ponds or a loss of connectivity in streams can decrease the number of crayfish.

Biocides and Biocontrol are not recommended because of their lack of specificity and damage to the surrounding environment. The most recommended strategy is utilizing natural or existing barriers along with physical removal that is timed with large flow events.

Management of an Invasive Bird: *Sturnus vulgaris* (European starling)

The European starling is an invasive bird that threatens agricultural cropland and native bird habitats. They are responsible for the transmission of 25 diseases, such as parrot fever and avian salmonellosis. However, because the Starling is found globally, complete eradication from its invasive range is unlikely but can be managed.

Detection Methods

Signs indicating their presence:

- Fruit crops have bird damage
- Bird nests in building cavities, trees, and street lights especially during summer months
- Large roosts and flocks of birds with black feathers and white specs
 - Starling is about 20 to 23 cm in length

Management

Frightening devices:

- Auditory repellents: loud noises, such as recorded starling distress or alarm calls, should be played with broadcast calling units
- Visual repellents: predator-bird decoys and automated scarecrows
- Auditory and visual repellents are most effective when used in combination. For example, an automated scarecrow can be placed next to broadcast calling units.
- It is important to rotate the type of auditory and visual repellent used to prevent habituation

Exclusion tactics:

- Plastic netting can be placed over high-value crops. The netting should extend to the ground and be tied securely to prevent birds from entering underneath.
- Wood, metal, or Plexiglass can be placed over ledges that are perching, nesting, or roosting sites. The material should be placed at a 45°-angle.

Hunting/Traps:

- Check with local and state laws before shooting any birds. Depredation permits may be needed.
- Trapping can be done with nesting boxes that have door traps. Traps must be 6.25 in. wide, 6.75 in. deep, and 15.25 in. high. Entry hole should be 1.75 in. diameter.
 - Trapped starling should be euthanized

Chemical:

- Starlicide, or DRC 1339, is a bird repellent that kills starlings in a single treatment
- Methyl anthranilate (MA) is a non-lethal chemical that can be added to scrap food or produce crops
 - MA causes irritation to Starling's mouth and nostrils
 - MA is a common food additive and rapidly degrades in the environment
- However, possible environmental side effects are unclear for either chemical and should be kept in mind. Avoid chemical treatment when possible.

Management of Invasive Tree Squirrel: *Sciurus niger* (fox squirrel)

The negative economic impacts of the fox squirrel are especially relevant to individuals living in urban and suburban cities. Those suffering from its ecological impacts include the western grey squirrel, insects, and trees with bark. Almost all management recommendations fall into the larger categories of “Lethal”, or “Non-Lethal” treatment. Although the lethal management strategies are proven to be effective, many refuse to take these approaches due to moral conflict.

Detection Methods

Signs indicating their presence:

- Damaged crops that have been eaten into
- Electrical wires that have been tampered with
- Damage to wooden objects such as buildings and telephone lines
- Damage to objects made of hard plastic material: sprinkler heads, utility covers, outdoor grill handles, benches, picnic tables, and the dashboards of utility vehicles

Lethal Management

Hunting:

- Game species that can be hunted year-round; must abide by the regulations established by California
- Shooting these animals is also allowed in instances when they’re damaging property or disrupting crops.

Traps/Poisons:

- Lethal traps are more favorable since relocation of these species is prohibited.
- Using poisons is illegal in the U.S because it also harms nearby plants and animals due to its lack of specificity in target.

Non-Lethal Management

Cutting down trees:

- Removing trees from cities specifically targets the fox squirrel because they are more prevalent than the natives in these urban and suburban regions.
 - However, there’s a more general, overarching ecological issue with this approach.
 - Trees modulate levels of greenhouse gases, contribute to the water cycle, and provide other organisms with a home.

Sterilization:

- Using immunocontraceptive vaccines such as GonaCon™
 - Developed by researchers at the USDA National Wildlife Research Center
 - Appeals to those who are against shooting or using lethal traps

Treatment for regions of overlap (where both natives and invasives cohabitate):

- Set lethal traps in nearby regions where only invasive squirrels are found.
- Introduce native species within a conserved region of overlap
- “Selective supplementary feeding” by placing weight sensitive food hoppers in trees within the region to selectively aid the lighter native species
 - The extent to which natives benefit is unclear, and supplementary feeding in general results in an increase in the incidence of disease transmission.

Management of Invasive Plant: *Arundo donax* (giant reed)

Arundo donax, the giant reed, is a perennial grass that is widespread in Los Angeles riparian watersheds and has vast economic and ecosystem impacts. Therefore, its removal and management has been an urgent issue for over a decade.

Detection Methods

Due to its prominence and conspicuous appearance, *A. donax* is detectable visually

Removal Strategy and Watershed Prioritization

- Top-down approach is most effective, targeting the top of the watershed and moving downstream as eradication is completed
- Highest priority watersheds are those that have already been treated and must be retreated
 - Other top priorities are those that are adjacent to fire-prone shrublands and those that have low levels of invasion.

Preventative Measures

- When eradication is not realistic, usually in physically inaccessible, dense populations of mature *A. donax*, the focus shifts to preventing spread and reducing invasion levels. Two methods are recommended.
 - Cut-regrow-spray: best used where *A. donax* is mature, overgrown, and there is little space between canes. Involves cutting the plants and spraying stumps with 3% to 5% glyphosate solution.
 - Mulch-excavate-spray: useful for treating high density areas.

Removal Mechanisms

Chemical Management:

- Warning: Chemicals used for treatment, such as glyphosate, may be carcinogenic and are genotoxic. Caution is advised, and mechanical removal should be considered before implementing chemical management plans.
- Glyphosate-based herbicides, such as Roundup are most effective, should be applied using 3% to 5% concentration between mid-August to early-November once per season
 - Foliar application with hand-held or backpack sprayers is best for plants <6 feet in height. Thoroughly wet the entirety of each plant while avoiding excess drip.
 - IPT cut stump treatment: Involves cutting the plants and spraying or painting stumps with 50% or 70% glyphosate solution, respectively.
 - Helicopter spraying can be used for physically inaccessible, dense populations with mature *A. donax*, but this is generally not recommended as eradication is generally not feasible.

Mechanical/Manual Management:

- Excavating: use a backhoe and grapple to remove small, dense stands

- Mulching: best used on sites with less than 30% slope and do not have sensitive terrain. Done with a hammer-flail mower attached to a tractor to cut top growth in the late fall or winter. It is followed up with herbicide spraying the next season and again in summer of the third year

Debris Management Techniques

- Vary depending on removal technique used or environment conditions
 - Leave in place: used immediately following herbicide spray
 - Burn on site: useful following any removal technique
 - Mulching, chipping, or composting: useful in remote areas
 - Remove debris: useful following mechanical/manual removal

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Appendix: High Priority Invasive Species in Los Angeles County, Second Report

Caulerpa Taxifolia (Algae)

A. Life History

Caulerpa Taxifolia is a siphonalean alga, the body of which is composed of a single large cell with multiple nuclei.¹ The invasive hybrid version readily colonizes many different types of substrate and can survive in a variety of depths and water temperatures.² The alga grows in dense mats, covering large patches of the benthos, and may grow rapidly (up to half an inch a day).³ It spreads readily via fragmentation, resulting in large populations that are genetically homogenous.⁴

a. Identification

Caulerpa Taxifolia is typically bright green ranging to darker green with a fern-like appearance.⁵ Its branches are typically between three and ten centimeters in length with a diameter of one to two millimeters.⁵ The branchlets (the “leaves” of the fern) are oppositely attached to the stem (pairs being on opposite sides directly across from each other, not offset), and are typically curving slightly towards the tip of the branch, tapered at both ends.

Individual plants can grow very large, reaching overall lengths up to ten feet. Aggregations of the algae can densely cover colonized areas, including rock and sand, and is capable of achieving 100% coverage in an area.³ Such dense coverage usually occurs in shallower areas, but the alga can be found at depths exceeding 150 feet.

Resources with detailed descriptions of *C. Taxifolia* for identification purposes are available from the University of Florida [here](#) and the University of Hawai'i [here](#).

B. Origin

The original form of *Caulerpa Taxifolia* is tropical regions, particularly the Caribbean

¹ Ramey, Victor. "Caulerpa Taxifolia." UFIFAS Center for Aquatic and Invasive Plants. June 2001. Accessed April 14, 2019. <https://plants.ifas.ufl.edu/plant-directory/caulerpa-taxifolia/>.

² Woodfield, Rachel. "Noxious Seaweed Found in Southern California Coastal Waters." NOAA Fisheries West Coast Region. Accessed April 13, 2019. https://www.westcoast.fisheries.noaa.gov/publications/habitat/caulerpa_taxifolia/noxious_seaweed_found_in_southern_california_coastal_waters.pdf.

³ NOAA Fisheries West Coast Region. "About Caulerpa." NOAA Fisheries West Coast Region. September 20, 2012. Accessed April 14, 2019. https://www.westcoast.fisheries.noaa.gov/habitat/aquatic_invasives/about_caulerpa.html.

⁴ Meinesz, A., Belsher, T., Thibaut, T. et al. Biological Invasions (2001) 3: 201. <https://doi.org/10.1023/A:1014549500678>

⁵ "Caulerpa Taxifolia." Marine Algae of Hawai'i. Accessed April 14, 2019. https://www.hawaii.edu/reefalgae/invasive_algae/chloro/caulerpa_taxifolia.htm.

Sea and Indian Ocean.⁶ The invasive hybrid is believed to have established itself from discharge of aquariums, where it is popular due to its coloration and hardness.⁷

C. Current Global/National Spread

Caulerpa Taxifolia is native to tropical regions. The invasive aquarium variant was found in the Mediterranean Sea around 1984, where it quickly spread.⁷ The alga now covers approximately 30,000 acres of seafloor proximate to several Mediterranean nations.^{4,7} More recently it has been reported in Australia as well, where control efforts are under way.⁷

Initial *Caulerpa* introduction into each area is attributed to discharge from aquariums. Once introduced, it reproduces and spreads via fragmentation. Pieces of *Caulerpa* do not float and have not been observed to grow on vessel hulls.⁷ However, equipment such as ship anchors and fishing gear—such as nets and lines—can carry pieces of the alga to new areas.

D. Distribution within Los Angeles County

Caulerpa Taxifolia was first identified in Southern California in June 2000 near Carlsbad.⁷ Shortly thereafter it was also found in Huntington Harbour, a relatively short distance from Los Angeles County and the Port of Long Beach.⁸ In both cases, identification of the alga was prompt and eradication efforts quickly began, helping to contain potential spread.⁹ The timely and effective response of government agencies, private actors, and non-governmental organizations that collectively formed the Southern California Caulerpa Action Team (SCCAT) has been lauded as “a model for invasive species rapid response.”⁹

At the time of this report, the author has found no definitive information on known presence of *Caulerpa* in Los Angeles County proper. However, given the virulent nature of the alga and the potential for point sources through illegal aquarium dumping, it is

⁶ Makowka, J. 2000. Monterey Bay National Marine Sanctuary Fact Sheet: *Caulerpa taxifolia*. Report to the Monterey Bay National Marine Sanctuary

⁷ NOAA Fisheries West Coast Region. "Caulerpa Taxifolia Source and Spread." NOAA Fisheries West Coast Region. September 20, 2012. Accessed April 14, 2019. https://www.westcoast.fisheries.noaa.gov/habitat/aquatic_invasives/source_and_spread_caulerpa.html.

⁸ Becerra, Hector. "Scientists Battle Algae Invader." Los Angeles Times. October 10, 2000. Accessed April 14, 2019. <https://www.latimes.com/archives/la-xpm-2000-oct-10-me-34352-story.html>.

⁹ Anderson, L.W.J. Biol Invasions (2005) 7: 1003. <https://doi.org/10.1007/s10530-004-3123-z>

necessary to maintain vigilant reporting practices and immediately implement containment efforts in response to any future outbreaks.

E. Ecological Impact

Caulerpa Taxifolia poses a significant ecological threat to areas it colonizes, including Southern California. Areas subject to invasion of *C. Taxifolia* in the past, notably the Mediterranean and some coastal areas of Australia, have experienced fundamental ecological shifts. The alga has demonstrated the ability to overgrow and displace native competitors, including seagrasses, corals, and other macroalgae.² In Southern California, there are concerns that *C. Taxifolia* could outcompete eelgrasses and other producer species, replacing indigenous marine flora.

Such an incident would create numerous secondary ecological disruptions. Areas invaded by *C. Taxifolia* in the past have experienced reduced biodiversity and abundance of native species.¹⁰ There is concern that areas where the alga attains dominance would be particularly disruptive to certain commercially valuable species like spiny lobster, California halibut, and sand basses.²

Furthermore, *C. Taxifolia* produces a toxin that makes it unpalatable to potential grazers, and as such there are no known species outside of the alga's native tropical range that consume it in any appreciable quantity.³ Replacement of native benthic producers could threaten the food source of grazing species.

F. Human Health Impact

There are no known human health hazards associated with *Caulerpa Taxifolia*.³

G. Economic Cost

As aforementioned, displacement of native marine flora by *C. Taxifolia* threaten to disrupt several commercially valuable species. Some of these species, such as spiny lobster, also function as recreational attractions for fishers and divers. The alga can also physically interfere with the use of fishing nets.² Proliferation of *C. Taxifolia* therefore poses a risk to commercial fishing and tourism in the Los Angeles County area.

Compounding the threat to tourism, Mediterranean areas that have experienced

¹⁰ Los Angeles Regional Water Quality Control Board. "Killer Algae." Killer Algae | Los Angeles Regional Water Quality Control Board. Accessed April 14, 2019. https://www.waterboards.ca.gov/losangeles/water_issues/programs/water_quality_issues/killer_algae_article.shtml.

infestations of *C. Taxifolia* in the past have reported harm to marine tourism industries, especially recreational boating and diving.²

H. Best Management Practices

The potential of *C. Taxifolia* to quickly spread from an initial point source makes preventing initial introduction, prompt response, and simultaneous measures to both eradicate and prevent fragmentary spread the core components of management.

Preventing Introduction

C. Taxifolia is listed as a noxious weed by the federal government, and as such is banned from importation.¹¹ Transport, sale, and possession of *C. Taxifolia* are illegal in the State of California per AB 1334, passed in 2001.¹² To prevent initial introduction, NOAA Fisheries for the West Coast Region recommends the following:³

- a. Enforce laws banning dumping of aquarium water in bodies of water. Encourage disposal of aquarium water in sinks or toilets, and disposal of solid material (e.g. rocks) from aquaria in trash cans.
- b. Dispose of *C. Taxifolia* and any solid material it is attached to from aquaria by placing them in plastic bags, freezing for 24 hours, then discarding in a trash can.
- c. Discourage sale and distribution of *C. Taxifolia*.

Vigilant Identification and Reporting Practices

Prompt identification and action helped quickly eradicate *C. Taxifolia* infestations in Southern California in the early aughts. Such practices are essential to preventing an initial colony from spreading uncontrollably. Early detection can be aided by the following practices:

- a. Regular surveys of bodies of water by individuals certified to conduct *Caulerpa* surveys. Surveyors may be certified through NOAA Fisheries or the California Department of Fish and Game.
- b. Immediately (within 24 hours) report any findings of *Caulerpa* to National Marine Fisheries Service Southwest Regional Office and the California Department of Fish & Game, South Coast Region.

¹¹ "Center for Aquatic and Invasive Plants." UFIFAS Center for Aquatic and Invasive Plants. Accessed April 19, 2019. <https://plants.ifas.ufl.edu/plant-directory/caulerpa-taxifolia/>.

¹² "Caulerpa Control Protocol Version 4." NOAA Fisheries West Coast Region. February 25, 2008. https://www.westcoast.fisheries.noaa.gov/publications/habitat/caulerpa_taxifolia/caulerpa_control_protocol_4_.pdf

- c. The full *Caulerpa* Control Protocol, Version 4 can be found [here](#). It includes contact information for the aforementioned agencies, survey procedures, and a survey reporting form.

Eradication Procedures

In the event of *C. Taxifolia* being found and reported, the *Caulerpa* Control Protocol dictates that eradication procedures will be the purview of NOAA Fisheries and the California Department of Fish & Game. The procedure to prevent spread while simultaneously removing the infestation is:

- a. **Tarping & Herbicide.** Successfully used to eradicate the nascent infestations of *C. Taxifolia* found in Southern California in the early aughts, this process involves covering the algae with a plastic tarp that is sealed to the bottom at its edges.² The tarp incorporates a port through which herbicide is introduced. The herbicide kills the algae, while the tarp serves the dual purpose of preventing fragments of *C. Taxifolia* from spreading to other areas and containing the herbicide such that it does not adversely affect other organisms in the area.

Argentine Ant – *Linepithema humile* (Insect)

A. Life History

Argentine ants, *Linepithema humile*, are a widely distributed invasive insect species. They are capable of forming vast colonies comprised of multiple nests.¹³ Each nest may contain numerous queens, potentially over one hundred, accompanied by thousands of workers.¹³ Nests within a colony appear to be non-antagonistic, as workers are able to move between the various nests without issue.¹³ This lack of intraspecific competition allows the ants to more densely colonize an area than many other species, contributing to their spread.

Argentine ants have robust population growth capabilities. Each queen can lay up to sixty eggs in a single day, with each egg progressing to the adult ant stage in approximately seventy-four days and a given worker living approximately twelve months.¹³ Eggs are laid year-round, except during the winter, with peak egg-laying occurring during spring and autumn.¹⁴ Worker females are sterile, but may be able to raise new queens in a de-

¹³ "Argentine Ant." Texas Invasive Species Institute. 2014. Accessed April 24, 2019. <http://www.tsusinvasives.org/home/database/linepithema-humile>.

¹⁴ Benois A, 1973. [English title not available]. (Incidence des facteurs écologiques sur le cycle annuel et l'activité saisonnière de la fourmi d'Argentine, *Iridomyrmex humilis* Mayr (Hymenoptera, Formicidae), dans la région d'Antibes) *Insectes Sociaux*, 20:267-295.

queened colony.¹⁵

a. Identification

Argentine ants are medium-sized, with workers typically measuring 2-3 mm in length, queens and males slightly larger.¹⁶ Their coloration is medium to dark brown, and their bodies are characteristically smooth and shiny, devoid of hairs on the dorsum of the head and the thorax.¹⁷ The ants possess a single-segmented petiole that resembles a scale and have no sting.



¹⁵ Keller L, Passera L, Vargo EL, 1989. [English title not available]. (Le remplacement des reines dans les colonies orphelines de la fourmi d'Argentine *Iridomyrmex humilis* Mayr. *Mécanismes et conséquences*) *Actes des Colloques Insectes Sociaux*, 5:117-120.

¹⁶ Danoff-Burg, James A. "Argentine Ant (*Linepithema Humile*).¹⁷ Invasion Biology Introduced Species Summary Project - Columbia University. Accessed April 24, 2019. http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/Linepithema_humile.html.

¹⁷ Global Invasive Species Database (2019) Species profile: *Linepithema humile*. Downloaded from <http://www.iucngisd.org/gisd/species.php?sc=127> on 24-04-2019.



Figure #: An Argentine ant. Photo by Alex Wild, from myrmecos.net via the University of California, Riverside Center for Invasive Species Research.

B. Origin

Argentine ants, as the name would imply, are native to South America. Their specific original range includes areas of Northern Argentina, Southern Brazil, Uruguay, and Paraguay.¹⁶ Their spread to non-native areas is attributed in all cases to accidental introduction by humans.

C. Current Global/National Spread

Argentine ants can be found globally. Beyond their native range in South America they have been identified in countries on every continent except Antarctica. These countries include Australia, France, Italy, Japan, Mexico, the United Kingdom, Spain, Switzerland, and South Africa. Additionally, they have been introduced to several smaller, more isolated countries and islands, such as Bermuda, Cuba, and New Zealand.¹⁷

Argentine ants were first identified in the United States in 1891 in New Orleans.¹⁶ They were found in California for the first time in 1907. They are now present in numerous areas along the California coast, in both the northern and southern parts of the state. Generally, Argentine ants prefer temperate climates that are not overly dry. Excessively hot or cold temperatures dissuade activity.¹⁸

¹⁸ "Linepithema Humile (Argentine Ant)." CABI Invasive Species Compendium. Accessed April 24, 2019. <https://www.cabi.org/isc/datasheet/30839>.

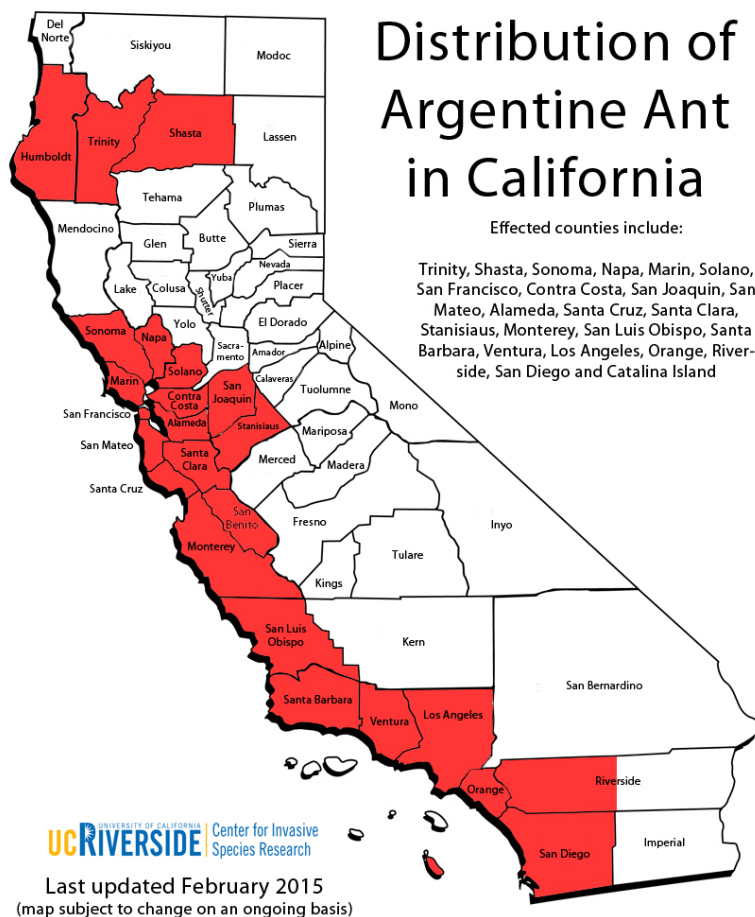


Figure #: Distribution of Argentine Ant in California as of February 2015. Image from University of California, Riverside Center for Invasive Species Research.

D. Distribution in Los Angeles County

While it is difficult to find exact distribution data for the Argentine ant in Los Angeles County at this time, by all accounts the species is ubiquitous throughout the coastal regions of Southern California.

E. Ecological Impact

Argentine ants have demonstrated an ability to outcompete and interfere with native ant species, leading to the eventual displacement of the native species. Several factors are responsible for this. Research in Northern California has found that Argentine ants are more proficient foragers than many native species.¹⁹ They locate food sources more consistently, exploit it with higher numbers of workers, and forage for longer during the day. Furthermore, Argentine ants appear to have a slight edge when in direct conflict with native species, and may prevent native species from establishing new colonies by

¹⁹ Human, K.G. & Gordon, D.M. *Oecologia* (1996) 105: 405. <https://doi.org/10.1007/BF00328744>

predating native species' queens.

This displacement of native ant species may disrupt food webs in the ecosystem.¹³ Certain predatory species, such as Blainville's horned lizard, will not substitute Argentine ants for their normal prey of native ant species.²⁰ Additionally, two native ant species with important regulatory ecological roles in California - army ants (*Neivamyrmex* spp.) and harvester ants (genera *Messor* and *Pogonomyrmex*) - have been shown to be especially vulnerable to ingress by Argentine ants.¹⁷ Argentine ants may also not perform the same role that some native species serve as seed dispersers or pollinators, creating another source of ecosystem disruption. They may also compete with native non-ant species, such as bees, for nectar.

Argentine ants also have a mutualistic relationship with several plant pest insects, such as aphids.²¹ The ants may cultivate, protect, and transport these pests, causing increased predation on flora.

F. Human Health Impact

Unlike some other species, Argentine ants do not sting or bite humans, and as such do not pose a direct threat to human health.²⁰ However, their dense populations can cause them to be a significant pest problem in urban areas.

G. Economic Cost

The primary economic threat posed by Argentine ants is to agriculture, due to their aforementioned tendency to cultivate pest insects like aphids. The pest insects produce honeydew, a sweet secretion, in return for which the ants herd and protect them. This may lead to higher densities of pest insects in agricultural areas, damaging crops.

More generally, the Argentine ant's tendency to be a nuisance pest in urban areas inflicts some degree of cost on residents and businesses in the form of pest control expenditures. In some cases they may infest building walls, causing damage to the structure.

H. Best Management Practices

The high numbers of Argentine ants in colonized area make full eradication difficult once the species is established.¹⁶ Furthermore, direct population reduction strategies are limited by the fact that most of the colonies are subterranean, rendering many insecticide

²⁰ Clarke, Chris. "Invasive Species Week: The Argentine Ant." KCET. February 17, 2016. Accessed April 24, 2019. <https://www.kcet.org/redefine/invasive-species-week-the-argentine-ant>.

²¹ Daugherty, Matt, and Kim Hung. "Argentine Ant." CISR. Accessed April 24, 2019. https://cizr.ucr.edu/argentine_ant.html.

treatments ineffective.²⁰ There are still some direct means of combating Argentine ants, but the best strategies are to prevent additional spread and limit colonization potential of areas.

a. *Prevention*

Argentine ants have been able to colonize areas and create high-density colonies most effectively when in areas modified by human activity, such as monoculture agricultural areas.¹⁷ Land management practices that allow for more natural ecosystem compositions can help prevent establishment of the species. Proactive surveys of potential nesting sites and food and water sources in both urban and rural areas (e.g. garbage cans) while limiting access to such resources can also help avoid initial infestation.

Proper inspection of potential vectors for introducing the ants to new areas (e.g. shipments of soil or plant material) can also prevent spread of the species.¹⁸

b. *Control*

Argentine ants have few natural predators or other controls in areas they have invaded.¹⁸ As such, the most effective ^{control} strategies are chemical-based.

Topical insecticide applications can help contain ant colonies, but are generally limited in effectiveness and carry the risk of side-effects on other species and human health.

Baits have been shown to be an effective means of reducing Argentine ant populations. Poisonous chemicals such as fipronil are combined with an edible attractant, which are transported by the ants back to the nest and may kill larvae.¹⁸ Such treatments can eradicate significant portions of ants in an area, but full eradication is unlikely and new colonies may move into vacated territory, requiring continuous treatment.²² In urban areas, barrier treatments with contact insecticides and bait can prevent incursion by ants inside buildings.

Milk Snail – *Otala Lactea* (Invertebrate)

A. Life History

Milk snails (*Otala lactea*) are a species of herbivorous, air-breathing, terrestrial snail. Nocturnal creatures, milk snails graze during night hours while remaining inactive and enclosed within their shell during the day. They have shown a tendency to spread

²² Vega, S. Y., and M. K. Rust. "Determining the Foraging Range and Origin of Resurgence after Treatment of Argentine Ant (Hymenoptera: Formicidae) in Urban Areas." *Journal of Economic Entomology* 96, no. 3 (2003): 844-49. Accessed April 26, 2019. doi:10.1603/0022-0493-96.3.844.

invasively in temperate, Mediterranean climates like that found in California, so long as appropriate breeding environments are available.²³ The snails typically lay eggs in loose soil or moist sand, laying over sixty eggs per clutch on average and producing two clutches per month.

a. Identification

Adult milk snails are approximately the size of a quarter.²⁴ Their shells exhibit high variability in coloration and pattern, which can cause confusion with other snail species like the white Italian snail (*Theba pisana*). The color of milk snail shells may be almost completely white ranging to heavy banding, exhibiting stripes that are brown or tan and which can be solid or marked with numerous dots or specks.

A key defining characteristic of the milk snail is that its umbilicus (the center of the shell's underside) is covered partly by the lip of the shell, and is usually a glossy brown. The shell size is usually between 28-39 mm wide and 18-24 mm high. Shells typically exhibit four to five whorls with very small ridges.²⁵ The columella (a rim or ridge on the lower lip of the shell by the opening) is extended, and usually shows very dark coloration.

B. Origin

Milk snails originated in the eastern Mediterranean and north Africa regions. They are believed to have been introduced to the United States by importation to Florida in the early 1900s.²³

C. Current Global/National Spread

Milk snails have been transported from their native range to several regions of the globe, including Argentina, Australia, the United States, and some Caribbean nations.²⁵ In the United States the snails have been identified in numerous states, including the Gulf Coast region (Florida, Mississippi, Texas, Louisiana), New England and the East Coast (Pennsylvania, New York, Maryland, Virginia, Georgia), some Midwest states (Missouri, Kentucky, Ohio) and California.²³

²³ "Milk Snail." Texas Invasive Species Institute. 2014. Accessed May 01, 2019. <http://www.tsusinvasives.org/home/database/otala-lactea>.

²⁴ "Introducing Your Los Angeles Snails!" Nature at NHMLA. May 15, 2018. Accessed May 01, 2019. <https://nhm.org/nature/blog/introducing-your-los-angeles-snails>.

²⁵ Capinera, John L., and Jodi White. "Terrestrial Snails Affecting Plants in Florida." Featured Creatures UF/IFAS. July 2014. Accessed May 01, 2019. https://entnemdept.ifas.ufl.edu/creatures/misc/gastro/terrestrial_snails.htm.

D. Distribution in Los Angeles County

Milk snails are one of the most common snails in LA County, but information on exact distribution is limited.²⁴ They can most commonly be encountered in natural areas and parks, and are most active after recent rainfall.

E. Ecological Impact

Milk snails are typically minor garden pests, but in areas like California where they can achieve larger populations their herbivorous behavior can cause significant detrimental impacts to plants and fruits, potentially including agricultural crops.²³ There is also evidence that they can outcompete native snail species, displacing them and disrupting native ecosystems.

F. Human Health Impact

In the course of writing this report no material identifying any human health impacts of milk snails (or lack thereof) was found.

G. Economic Cost

As aforementioned, milk snails are herbivorous, and as such can may be detrimental to garden plants and crops, especially fruits. However, at the time of this report, no material detailing specifics or monetary valuation of damages caused by the species has been identified.

H. Best Management Practices

At the time of this report, limited information has been found on effective management practices for milk snails. Recommended strategies include encouraging human harvesting for consumption, as the snails are edible; land management practices that avoid creating appropriate habitat for the snails; and avoiding importation of the snails.²³

Largemouth Bass - *Micropterus Salmoides* - (Fish)

A. Life History

Largemouth bass is a species of carnivorous freshwater fish whose diet mainly consists of smaller fish, as well as plankton and frogs during juvenile stages.²⁶ They may also predate on crustaceans, rotifers, crayfish, and insects at various life stages. The fish typically inhabit the shallow, warmer areas of ponds, lakes, rivers, and other bodies of fresh water.²⁷

Largemouth bass reach sexual maturity when they reach a length of between 18 and 21 cm for males and 20 to 25 cm for females. Spawning occurs in the spring, usually March or April, and may continue into June. Males construct nests in the floor of the water body by clearing a depression in which females lay eggs, which hatch between two and seven days after fertilization. Juveniles will usually reside in the nest for five to eight days after hatching, during which they are guarded by the male. This guarding behavior continues for two to four weeks, after which juveniles practice schooling behavior until they grow large enough to become solitary hunters.

a. Identification

Largemouth bass exhibit significant variation in growth patterns based on environmental factors. By the third year a typical bass is approximately sixteen inches in length.²⁸ Their most definitive physical characteristic is a black lateral stripe running along the upper portion of the body. Other notable features include a large mouth, brown eyes, nine dorsal spines, and three anal spines. Specific minute features (e.g. number of fin rays, scale counts) can be found online from the University of California Division of Agriculture and Natural Resources: California Fish Website.

B. Origin

Largemouth bass' native range includes several bodies of water in North America. These include the Mississippi River, basins along said river, Hudson Bay, the Great Lakes region, and drainages along both the Atlantic and Gulf Coast areas in the Southeastern

²⁶ "Largemouth Bass." Fisheries and Oceans Canada. Accessed May 09, 2019. <http://www.dfo-mpo.gc.ca/species-especes/profiles-profil/largemouthbass-achigangrandebouche-eng.html>.

²⁷ University of California. "California Fish Species." California Fish Species - California Fish Website. Accessed May 09, 2019. <http://calfish.ucdavis.edu/species/?uid=84&ds=698>.

²⁸ "Largemouth Bass (*Micropterus Salmoides*)." Texas Parks and Wildlife. Accessed May 09, 2019. <https://tpwd.texas.gov/huntwild/wild/species/lmb/>.

United States.²⁹ They have spread worldwide largely due to human introduction, both deliberately for sport fishing and inadvertently.

C. Current Global/National Spread

Largemouth bass are widespread in the Americas, having been introduced into numerous parts of the United States, Mexico, and Canada, as well as some regions of Central and South America.²⁸ Reports also show records of the fish being observed in dozens of countries around the world, in regions that include Europe (e.g. Germany, Austria, Sweden, Spain), Eastern Europe (e.g. Czech Republic, Ukraine), East Asia (e.g. China, Taiwan, Korea), the Mediterranean (e.g. Italy, Cyprus), North Africa (e.g. Egypt, Morocco), Sub-Saharan Africa (e.g. South Africa, Mozambique, Lesotho), and Eurasia (e.g. Russia).³⁰

Within the United States, the fish has been reported in a significant majority of states, ranging from the East Coast to the Midwest to the West Coast, and even Alaska.²⁸

D. Distribution in Los Angeles County

At the time of this report, information on specific bodies of water within Los Angeles County where Largemouth bass can be found has not been identified. Notable locations near the county where the fish can be found include Big Bear Lake, Canyon Lake, Diamond Valley Lake, Castaic Lake, and Lake Elsinore.³¹

E. Ecological Impact

Introduction of Largemouth bass into a body of water has been shown to have a severe negative impact on native organisms. The primary mechanisms of this disruption are predation of smaller native species by the bass and outcompeting other predators for prey.³⁰ In particular, research has shown that largemouth bass significantly increase predation pressure on odonates (dragonflies and damselflies) and crayfish.³² Studies have also shown that the bass predate heavily on water-column fish as opposed to benthic

²⁹ Pam Fuller, and Matt Neilson, 2019, *Micropterus salmoides* (Lacepède, 1802): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, <https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=401>, Revision Date: 2/22/2019, Peer Review Date: 4/1/2016, Access Date: 5/8/2019

³⁰ "Micropterus Salmoides." GISD. Accessed May 09, 2019. <http://www.iucngisd.org/gisd/species.php?sc=94>.

³¹ "California Bass Fishing." All About Fishing. Accessed May 10, 2019. <https://www.aa-fishing.com/ca/california-bass-fishing.html>.

³² Maezono, Yasunori, Raita Kobayashi, Miki Kusahara, and Tadashi Miyashita. "Direct And Indirect Effects Of Exotic Bass And Bluegill On Exotic And Native Organisms In Farm Ponds." *Ecological Applications* 15, no. 2 (2005): 638-50. doi:10.1890/02-5386.

fish.³³

Largemouth bass introduction leads to an overall reduction in numerous species, including both native and other introduced species of fish, shrimp, odonates, and crayfish.³² Given the heavy predatory impact bass populations may have, this can lead to severe disruption of preexisting food webs, potentially resulting in extinction or extirpation native species.³⁴ In California, introduction of largemouth bass may have contributed to reductions in the populations particular amphibious species such as the California tiger salamander (*Ambystoma californiense*) and ranid frogs.²⁸

F. Human Health Impact

No information has been found linking Largemouth bass to adverse human health impacts of any kind at the time of this report.

G. Economic Cost

Unlike many other invasive species, Largemouth bass has a sizeable positive economic impact. This is primarily driven by the sizeable sport fishing industry, within which Largemouth bass is one of the most popular game fishes. A report by the American Sportfishing Association (ASA) found that the national recreational fishing industry generates over \$100 billion of economic activity annually, though it should be noted that the ASA is an industry group with incentives to portray the industry as economically valuable so as to avoid environmental regulation.³⁵ This report estimated that over \$4 billion of this activity is in California.

Academic research quantifying the economic impacts of bass fisheries also shows that they can generate significant economic activity through expenditures by anglers for proximate goods and services, job creation, and other indirect means.^{36,37} Evaluation of particular fisheries has found wide variation in the magnitude of a single fishery's

³³ Almeida, David, Ana Almodóvar, Graciela G. Nicola, Benigno Elvira, and Gary D. Grossman. "Trophic Plasticity of Invasive Juvenile Largemouth Bass *Micropterus Salmoides* in Iberian Streams." *Fisheries Research* 113, no. 1 (2012): 153-58. doi:10.1016/j.fishres.2011.11.002.

³⁴ "Largemouth Bass." Fisheries and Oceans Canada. Accessed May 10, 2019. <http://www.dfo-mpo.gc.ca/species-especies/profiles-profils/largemouthbass-achigangrandebouche-eng.html>.

³⁵ Southwick Associates. "Economic Contributions of Recreational Fishing: U.S. Congressional Districts." American Sportfishing Association. October 2015. https://asafishing.org/uploads/Congressional_District_Sportfishing_Impacts_2015_Report.pdf

³⁶ Chen, R. J., K. M. Hunt, and R. B. Ditton. "Estimating the Economic Impacts of a Trophy Largemouth Bass Fishery: Issues and Applications." *North American Journal of Fisheries Management* 23, no. 3 (2003): 835-44. doi:10.1577/m02-014.

³⁷ Lothrop, Ryan L., Terry R. Hanson, Steven M. Sammons, Diane Hite, and Michael J. Maceina. "Economic Impact of a Recreational Striped Bass Fishery." *North American Journal of Fisheries Management* 34, no. 2 (2014): 301-10. doi:10.1080/02755947.2013.869279.

economic impact, however, ranging from hundreds of thousands to multiple millions of dollars annually. Special events such as tournaments—which may attract large numbers of non-local anglers—can be especially beneficial to local economies.³⁸ Besides general economic benefits, such activity generates revenue for government through permitting and taxes.

H. Best Management Practices

There is little information available on established management practices for largemouth bass. This is due in part to the notorious difficulties in managing aquatic invasive species.³⁹ Counter to invasive species concerns, human activity has historically focused on introducing and stocking bass for recreational fishing. Some government entities, such as Fisheries and Oceans Canada, are conducting ongoing research on the species, which may assist in identifying useful management practices.³⁴

Research on other bass species has shown some promising avenues for controlling invasive populations. These strategies include electrofishing (the use of electric current to stun and net fish), explosives, chemical treatments with piscicides (e.g. rotenone, antimycin-A, Supaverm), and biological control via introduction or enhancement of pathogens and parasites.⁴⁰ Sterilization and manipulation of environmental factors (e.g. water temperature, water level, dissolved oxygen, and benthos composition) may be other effective means of directly reducing bass population or hindering reproduction. Many of these factors carry the risk of side effects, however, and will require further research to gauge effectiveness on Largemouth bass specifically.

Some potential strategies—such as angling, netting, and enhancing or introducing predators—are typically ineffective or inapplicable to a high trophic level predator like Largemouth bass. Similarly, attempting to establish biological predatory controls on juvenile bass may be ineffectual due to the guarding behavior exhibited by males of the species.

³⁸ Snellings, Patrick Lee. "Economic Value of the Tournament Black Bass Fishery on Lake Guntersville, Alabama." *Auburn University School of Fisheries, Aquacultures and Aquatic Sciences*. May 9, 2015. https://etd.auburn.edu/xmlui/bitstream/handle/10415/4607/Economic_Value_of_Tournament_Black_Bass_Fishin_g_on_Lake_Guntersville_15_05_07.pdf?sequence=2&isAllowed=y

³⁹ Zanden, M. Jake Vander, and Julian D. Olden. "A Management Framework for Preventing the Secondary Spread of Aquatic Invasive Species." *Canadian Journal of Fisheries and Aquatic Sciences* 65, no. 7 (2008): 1512-522. doi:10.1139/f08-099.

⁴⁰ Loppnow, Grace, Kris Vascotto, and Paul Venturelli. "Invasive Smallmouth Bass (*Micropterus Dolomieu*): History, Impacts, and Control." *Management of Biological Invasions* 4, no. 3 (2013): 191-206. doi:10.3391/mbi.2013.4.3.02.

Common Carp – *Cyprinus Carpio* (Fish)

A. Life History

The common carp is an omnivorous freshwater fish classified as one of the hundred worst invasive species in the world.⁴¹ They are typically found in static or slow-flowing bodies of water, especially lakes and wetlands at relatively low altitudes, as well as some brackish water bodies in coastal regions.⁴² Carp have a significant capacity to modify and disrupt environments, and as such have been labeled "ecosystem engineers." A key cause of this impact is their foraging behavior, which can lead to widespread physical alteration of the benthos in bodies of water they occupy.

Once a female carp lays her clutch of between one and five hundred thousand eggs—done when water temperatures are warm (usually April to June in the United States) —hatching occurs rapidly, within two days.^{41,42} Larvae predate on plankton and crustaceans until they reach 1-4 inches in length, undergoing rapid growth which allows for them to avoid predation. They usually reach sexual maturity within three to four years, with adult carp weighing eight to ten pounds and measuring 12-25 inches in length. Typical carp may live between thirteen and twenty years, though a record specimen in captivity lived to be 47.⁴²

a. Identification

As aforementioned, adult common carp usually weigh eight to ten pounds and measure 12-25 inches in length. They exhibit varied coloration, including green, yellow, silver, bluish-green and goldish-brown.⁴¹ The ventral area (the belly of the fish) is white or yellow. Some variants of the species may exhibit a wider range of colors or anomalous scale patterns.⁴²

Physical characteristics of common carp include serrated spines present in the fins, small eyes, and thick lips. Two barbels (thin anatomical structures similar to whiskers, such as those found on catfish) can be found at each corner of the mouth. Other identifying features include 3-4 dorsal spines, 17-23 dorsal soft rays, 2-3 anal spines, and 5-6 anal soft rays.

B. Origin

⁴¹ "Common Carp." Texas Invasive Species Institute. Accessed May 10, 2019. <http://www.tsusinvasives.org/home/database/cyprinus-carpio>.

⁴² "Cyprinus Carpio." GISD. Accessed May 10, 2019. <http://www.iucngisd.org/gisd/species.php?sc=60>.

Common carp originated in the Caspian Sea in Southwestern Eurasia.⁴³ They are believed to have migrated from there to other bodies of water in Europe and Asia. Some sources indicate that their natural range also includes portions of the Middle East (e.g. the Euphrates River).⁴²

C. Current Global/National Spread

Common carp are widely distributed globally, due primarily due to intentional introduction by humans for use as a food source, and accidental release from aquaria.⁴² Human assistance of the fish's spread goes back centuries, with evidence that the Romans assisted their establishment in the Danube River of Europe. Carp have been identified in numerous countries on nearly every continent. They are ubiquitous in European and North American nations, as well as many former Soviet satellite countries. Carp have been identified in South America (e.g. Brazil, Venezuela), the Caribbean (e.g. Dominican Republic, Cuba), Eurasia and East Asia (e.g. Russia, China, Vietnam), Australia, Africa (e.g. Kenya, Ghana, South Africa) and numerous island states (e.g. French Polynesia, Fiji).

While exact details are subject to debate, common carp are believed to have been introduced in the United States around the late 1800s.⁴³ It was dispersed through intentional introduction and stocking, and spread into non-enclosed bodies of water through accidental release, dam breakage, and similar events. Common carp are currently present in every state in the United States except Alaska, with records indicating the most observations in the general Mississippi delta. Observations in California are most concentrated along the central coast (including the San Francisco Bay Area), the Los Angeles area, and the central valley.

D. Distribution in Los Angeles County

In 2008, Common carp were one of the most fish identified in a survey of the Los Angeles River.⁴⁴ Historically, carp have been found in the Los Angeles County area for decades, being identified in the Bouquet, Chatsworth, Fairmont and San Fernando Reservoirs in the early 1960s.⁴⁵ Currently, the California Office of Environmental Health and Hazard Assessment identifies several Los Angeles area bodies of water as having carp present, including Castaic Lagoon, Castaic Lake, Legg Lake, Little Rock Reservoir,

⁴³ "Cyprinus Carpio." NAS - Nonindigenous Aquatic Species. Accessed May 10, 2019. <https://nas.er.usgs.gov/queries/factsheet.aspx?speciesID=4>.

⁴⁴ Friends of the Los Angeles River. "State of the River 2: The Fish Study." September 2008. <https://ucanr.edu/blogs/Green/blogfiles/5222.pdf>

⁴⁵ Davis, Sterling P. "Commercial Freshwater Fisheries of California." *California Fish and Game* 49, No. 2 (1963): 84-94.

Magic Johnson Lakes, Puddingstone Reservoir, and Santa Fe Dam Lake.⁴⁶

E. Ecological Impact

Common carp have a profound ecological impact on aquatic areas. As omnivores, carp can increase predation pressure on both aquatic flora and certain classes of fauna.⁴¹ Their most common feeding behavior is to forage in the benthos, rooting for plants and fish eggs.⁴² They have also been found to consume insects, crustaceans, annelids (worms), mollusks, and seeds. Carp predation can also increase competition for native fish species. This, combined with their predation on other species' eggs, can decrease populations of native fish. Such has been the case in California.

The foraging behavior of carp can cause significant disturbance to the ecosystem. Their foraging behavior in the benthic environment can uproot or damage aquatic plants. When sufficiently widespread, disruption of the plants in an aquatic ecosystem—usually crucial to the overall health and functioning of that ecosystem—can cause fundamental ecosystem change, decreasing macrophyte (larger aquatic plants) populations and increasing algae counts by releasing nutrients from the benthos.⁴⁷ Decreased aquatic plant coverage may cause declines in the populations of dependent species, including fish, amphibians, and reptiles.

This activity, combined with the propensity of Common carp to excrete phosphorus, contributes to decreased water quality, higher turbidity, and higher algae counts.⁴⁸ Overall, this can degrade habitat for many native species, reducing biodiversity and threatening endangered species.

F. Human Health Impact

As aforementioned, the disturbance of the benthos by carp can suspend silt and nutrients in the water column, and carp are known to excrete phosphorus.⁴² This can degrade water quality, potentially to the point where it becomes unsuitable for swimming.

G. Economic Cost

Common carp has a mixed reputation as a sport fish; in some cases, anglers may find it attractive because of the thrashing behavior it exhibits when hooked.⁴¹ However, in many

⁴⁶ "Fish Advisories." OEHHA. Accessed May 11, 2019. <https://oehha.ca.gov/fish/advisories>.

⁴⁷ Miller, S. A., and T. A. Crowl. "Effects of Common Carp (*Cyprinus Carpio*) on Macrophytes and Invertebrate Communities in a Shallow Lake." *Freshwater Biology* 51, no. 1 (2006): 85-94. doi:10.1111/j.1365-2427.2005.01477.x.

⁴⁸ Parkos, Joseph J., III, Victor J. Santucci, Jr., and David H. Wahl. "Effects of Adult Common Carp (*Cyprinus Carpio*) on Multiple Trophic Levels in Shallow Mesocosms." *Canadian Journal of Fisheries and Aquatic Sciences* 60, no. 2 (2003): 182-92. doi:10.1139/f03-011.

areas it is considered a pest, decreasing stocks of more attractive options for recreational fishing.⁴⁹ While carp are a valuable protein source in many developing and undeveloped countries, they are not unequivocally considered a prime sport fish in the United States.⁴²

H. Best Management Practices

Common carp can be contained and controlled using a variety of methods, ranging from traditional spread prevention techniques to physical and chemical controls. Several other methods have also been identified as promising, but may require careful evaluation of their practicality and further research as to potential undesired consequences.

Preventing the spread of carp to unaffected bodies of water can be accomplished with exclusion measures such as physical barriers, electric barriers, bubble barriers, and acoustics.⁴² In some cases, non-physical barriers may be more practical to implement at sites like intake pipes to prevent fish from swimming inside, as opposed to large scale.

Common carp population control can be accomplished through numerous means. Physical strategies include seining, particularly during winter months; direct harvesting; trapping; and water level manipulation.^{42,50} However, there is evidence that direct harvesting is insufficient to reduce carp populations by desirable amounts outside of areas like Europe where they are considered a desirable target fish.

Chemical control options for common carp include Rotenone, which has shown to be a relatively safe chemical treatment option in the past; use of fish pheromones to change behavior as part of a multifaceted management plan; and using toxic baits.⁵⁰ Research in Minnesota indicates that carp are unable to avoid poisoned baits, and that groups learn to aggregate in areas of lakes where food sources are placed. These factors make bait-and-switch control techniques an attractive option. Pheromone treatments may also be an effective way of concentrating carp for seining or other means of physical removal.

Several promising methods of biological control have been identified, though some may be controversial and/or require further research on feasibility of implementation. Deliberately spreading the naturally occurring carp-affecting virus Rhabdovirus carpio was first proposed in the 1970s, and more recent work has identified the Carp Edema Virus and Koi Herpes Virus as potential carp population control agents. Early research on the introduction or enhancement of other fish species, particularly the bluegill, as a means of increasing predation on carp eggs has yielded positive results.⁵⁰

⁴⁹ Hagan, Melissa. "Cyprinus Carpio." NEMESIS: National Exotic Marine and Estuarine Species Information System. Accessed May 12, 2019. http://invasions.si.edu/nemesis/CH-IMP.jsp?Species_name=Cyprinus_carpio.

⁵⁰ "Common Carp Research at MAISRC." Minnesota Aquatic Invasive Species Research Center (MAISRC). July 05, 2018. Accessed May 12, 2019. <https://www.maisrc.umn.edu/commoncarp-research>.

Strategies still in the developmental stage include immunocontraception (using a genetically engineered virus to deliver a gene treatment to carp that prevents reproduction); and introducing inducible fatality genes, a strategy that involves breeding carp with genetic components that make them susceptible to a lethal treatment of a particular substance (e.g. zinc).⁴²

Traditional sterility treatments are unlikely to be effective, as recent research has shown that common carp can regenerate reproductive organs after a gonadectomy procedure.⁵⁰ However, genetic sterility treatments may be viable with further research.

Bluegill – *Lepomis macrochirus* (Fish)

A. Life History

Bluegills are omnivorous freshwater fish that typically reside in low-elevation bodies of water.⁵¹ They prefer warmer waters, though there is some inconsistent information published regarding what is considered their ideal temperature, and as such are found in shallow lakes, reservoirs, ponds, and streams.⁵² Individuals tend to reside in a limited area for their lifespan (usually no longer than 6 years), though the species shows flexibility in where in the water column they spend time.

Spawning occurs when water temperatures increase, reaching at least 70 degrees Fahrenheit (typically May to June in the United States).⁵² Males create nests in shallow water--usually 1-2 feet deep--fanning out a depression in the benthos.⁵³ They prefer a gravelly floor composition, and many spawning males may create a congregation of nests in close proximity to each other.⁵⁴ Each nest is typically 20-30 cm wide and 5-15 cm deep.⁵¹ Females lay eggs in the nest, where they are fertilized and subsequently defended by the male, with each nest typically holding between 2,000 and 18,000 eggs (though significantly higher numbers can occur). The eggs are defended aggressively by males against predation, and will usually hatch within a 2-3 day window. Juveniles will migrate to the shelter of aquatic plants, where they reside until sufficiently grown (approximately 6-7 weeks later).

Bluegills may predate on a variety of food sources, with their preferred prey being aquatic insects and insect larvae.⁵⁴ They may also feed on plankton (especially during the juvenile stage), snails, small fish, fish eggs, and crayfish.⁵¹ Aquatic plants and algae are also an option, but long-term reliance on these as food sources may cause developmental problems, and thus they are not preferred.

a. Identification

Adult bluegills typically measure about 7.5 inches in length, with the highest recorded length of an individual being 16 inches.⁵³ The maximum weight recorded for an individual is 4 lbs. 12 oz.⁵² They exhibit a titular iridescence,

⁵¹ "California Fish Species - Bluegill." California Fish Website. Accessed May 13, 2019. <http://calfish.ucdavis.edu/species/?uid=12&ds=241>.

⁵² Park, Kaili. "Bluegill, *Lepomis macrochirus*." University of Washington. December 5, 2014. http://depts.washington.edu/oldenlab/wordpress/wp-content/uploads/2015/09/Lepomis_macrochirus_Park_2014.pdf

⁵³ "Bluegill." U.S. Fish and Wildlife Service - Fish and Aquatic Conservation. Accessed May 13, 2019. <https://www.fws.gov/fisheries/freshwater-fish-of-america/bluegill.html>.

⁵⁴ "Bluegill (*Lepomis Macrochirus*)." Texas Parks and Wildlife. Accessed May 13, 2019. <https://tpwd.texas.gov/huntwild/wild/species/bgl/>.

giving them a shiny bluish-purple color, with a black spot on their dorsal fin and thin, vertical black stripes on their sides.⁵¹ Other key identifying characteristics include 11-12 anal rays, 13-14 pectoral rays, 10-12 dorsal rays, 5 pelvic rays, 3 anal spines, and 10 dorsal spines. Additional noted features can be viewed at the University of California California Fish Website.

During breeding season, male coloration may change significantly, becoming olive-colored or bronze on the dorsal and lateral aspects, orange on the breast, and the pelvic and anal fins exhibit an iridescent black color.⁵¹

B. Origin

Bluegill originated in North America. Their native range is considered to include the Great Lakes region, the entirety of the Mississippi River delta, and coastal drainages ranging from the Virginia area on the Atlantic coast to the Texas region of the Gulf of Mexico.⁵⁵

C. Current Global/National Spread

Bluegill are well-established throughout the United States, Mexico, and Canada.⁵⁶ Within the continental United States, every state has recorded observations of bluegill in at least some areas. The densest observations have been recorded along the eastern seaboard, the coastal areas of the western states, and along major river systems in the midwest and northwest.⁵⁵ Information on bluegill introduction and distribution internationally is limited; several academic studies have focused on the presence of bluegill in East Asian nations, specifically Japan and Korea.^{57 58}

D. Distribution in Los Angeles County

Bluegill are well-established within Los Angeles County. The California Office of Environmental Health Hazard Assessment's published fish advisories indicate the presence of bluegill in several bodies of water within the county, including Castaic Lake,

⁵⁵ "Lepomis Macrochirus." USGS NAS - Nonindigenous Aquatic Species. Accessed May 13, 2019. <https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=385>.

⁵⁶ NatureServe 2013. *Lepomis macrochirus*. *The IUCN Red List of Threatened Species* 2013: e.T61260A18235651. <http://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T61260A18235651.en>. Downloaded on 13 May 2019.

⁵⁷ Kawamura, Kouichi, Ryuji Yonekura, Osamu Katano, Yoshinori Taniguchi, and Kenji Saitoh. "Origin and Dispersal of Bluegill Sunfish, *Lepomis Macrochirus*, in Japan and Korea." *Molecular Ecology* 15, no. 3 (2006): 613-21. doi:10.1111/j.1365-294x.2006.02823.x.

⁵⁸ Maezono, Yasunori, and Tadashi Miyashita. "Community-level Impacts Induced by Introduced Largemouth Bass and Bluegill in Farm Ponds in Japan." *Biological Conservation* 109, no. 1 (January 2003): 111-21. doi:10.1016/s0006-3207(02)00144-1.

Legg Lake, Little Rock Reservoir, Magic Johnson Lakes, Puddingstone Reservoir, and Santa Fe Dam Lake.⁵⁹

E. Ecological Impact

Bluegill have a significant ecological impact on areas where they are found. Their omnivorous feeding habits allow them to exert predation pressure on many different organisms, both flora and fauna, while their prolific spawning creates large, dense populations.⁵² Their ecological impact is furthered by their fairly high resiliency to various environmental conditions, allowing them to thrive in many different aquatic areas.

A primary mechanism for ecological impacts of Bluegill is their ability to outcompete other fish species for prey.⁵² Combined with their predatory pressure, the fish can cause notable reductions in populations of various other organisms, including fish, crustaceans, and odonates (dragonflies).⁵⁸ In California, bluegill are responsible for reductions in a few specific species, including the Sacramento perch and a few amphibian species (e.g. California Tiger Salamander, ranid frogs).

There is evidence that these disruptions can in turn cause a trophic cascade, causing fluctuations in the populations of various other organisms (e.g. tadpoles), though this may be due to other invasive species (e.g. bass).⁵⁸

F. Human Health Impact

At the time of this report, no information has been found linking bluegill to positive or negative human health outcomes.

G. Economic Cost

While not considered a prime candidate for recreational fishing, bluegill are nonetheless valuable for the recreational and sport angling industry, an economic positive.⁵⁴ Bluegill are also a prey fish for bass, the most popular and valuable recreational fish in the United States and California. However, at the time of this report, little information has been found quantifying the magnitude of the bluegill fishing industry.

H. Best Management Practices

Given the popularity of bluegill for recreational and sport fishing, many management practices focus on measures designed to perpetuate a healthy population for this

⁵⁹ "Fish Advisories." OEHHA. Accessed May 14, 2019. <https://oehha.ca.gov/fish/advisories>.

purpose.⁶⁰ There are few restrictive or population reduction measures in place in the United States.⁵² Korea and Japan have prohibited bluegill release in an attempt to prevent the species' spread.

Given the lack of established practices in controlling and managing bluegill, further research will be required. It may be possible to institute generalist treatments (e.g. physical barriers) and measures that have been effective in controlling other invasive fish species with the goal of controlling bluegill.

⁶⁰ "Sunfish Management - Minnesota DNR." Minnesota Department Of Natural Resources. Accessed May 15, 2019. <https://www.dnr.state.mn.us/fish/sunfish/management.html>.

Wattles – *Acacia* sp. (Plant)

A. Life History

Acacia is a genus of trees and shrubs that includes several invasive species. The most globally notable species of this group is Black Wattle (*Acacia mearnsii*), but several species have been identified in California, including Blackwood acacia (*Acacia melanoxylon*), Cootamundra wattle (*Acacia baileyana*), and Silver wattle (*Acacia dealbata*).^{61 62 63}

Some *Acacia* species are able to reproduce and spread virulently by producing large numbers of hardy seeds.⁶⁴ These seeds may remain viable for decades (up to 50 years in the case of *Acacia mearnsii*) and can be spread via water or human action.⁶¹ In some cases fire events can cause mass germination. The role of fire in facilitating the spread of *Acacia* is especially relevant in fire-prone California. Research conducted on the species *Acacia suaveolens* indicated that elimination of the seed bank in an area required long fire-free periods.⁶⁵ Species like Blackwood acacia may also spread via clonal reproduction, using their root systems.⁶¹

Acacia species prefer dry, temperate areas or moist, tropical climates.⁶⁴ However, they have some flexibility in the temperatures and rainfall they can tolerate. For *Acacia mearnsii*, these figures are 6.6-22.8 dm annual precipitation and 14.7-27.8°C annual mean temperature. Especially dry or poor soils are not conducive to *Acacia* growth. Growth patterns vary species to species, but many species reach maturity within a few years (e.g. 2-5 years for *Acacia suaveolens*), and achieve maximum reproductive capacity a few additional years later.⁶⁵ *Acacia* species are also leguminous, and as such can fix nitrogen from the air.

a. Identification

Acacia species can be visually identified by physical features, including leaf structure and flowers. *Acacia* leaves resemble ferns or feathers due to a structure

⁶¹ "Acacia Melanoxylon Profile." California Invasive Plant Council. May 08, 2018. Accessed May 17, 2019. <https://www.cal-ipc.org/plants/profile/acacia-melanoxylon-profile/>.

⁶² "Acacia Baileyana Risk." California Invasive Plant Council. October 12, 2017. Accessed May 17, 2019. <https://www.cal-ipc.org/plants/risk/acacia-baileyana-risk/>.

⁶³ "Acacia Dealbata Profile." California Invasive Plant Council. May 08, 2018. Accessed May 17, 2019. <https://www.cal-ipc.org/plants/profile/acacia-dealbata-profile/>.

⁶⁴ "Acacia Mearnsii." GISD. Accessed May 17, 2019. <http://www.iucngisd.org/gisd/species.php?sc=51>.

⁶⁵ Auld, Tony D. "Population Dynamics of the Shrub *Acacia Suaveolens* (Sm.) Willd.: Survivorship throughout the Life Cycle, a Synthesis." *Australian Journal of Ecology* 12, no. 2 (2006): 139-51. doi:10.1111/j.1442-9993.1987.tb00935.x.

of small leaflets along a stalk, though in some species the leaflets have been lost, leaving only a flattened stalk.⁶⁶ Stalks may have thorns. Leaves are usually dark green and have fine hairs.⁶⁴

Acacia flowers are somewhat spherical or globular in shape, and often appear in tight clusters or sprays. Their flowers are highly fragrant and have a yellow or white coloration.

Acacia fruits are legumes. Appearance varies widely across species, including dark brown pods (*Acacia mearnsii*).

Acacia plants can grow several meters tall, reaching heights of twenty meters in some species.

B. Origin

Acacia species are generally native to Australia and Africa, though some are considered indigenous to Central America and the Caribbean.⁶⁷ Some species, notably *Acacia mearnsii*, have been actively cultivated globally for forestry purposes, while several species have been used as ornamental plants.^{64 66}

C. Current Global/National Spread

Acacia species have been identified in numerous countries outside their native range. The most notable invasive species of the group, *Acacia mearnsii*, has been reported in global regions including East Asia (e.g. China, Japan), Europe (e.g. France, Spain), Africa (e.g. Madagascar, Uganda, South Africa) and several island nations (e.g. New Zealand, Seychelles).⁶⁴ Within the United States, invasive *Acacia* plants have been reported most commonly in Florida and the coastal regions of California, as well as Hawaii and Idaho.⁶⁸

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D. Distribution in Los Angeles County

Observations of various *Acacia* species in Los Angeles County are mostly concentrated in along the coast, though some species (e.g. *Acacia mearnsii*) have been more

⁶⁶ The Editors of Encyclopædia Britannica. "Acacia." Encyclopædia Britannica. March 22, 2019. Accessed May 18, 2019. <https://www.britannica.com/plant/acacia>.

⁶⁷ "Acacia Farnesiana." GISD. Accessed May 18, 2019. [http://www.iucngisd.org/gisd/speciesname/Acacia farnesiana](http://www.iucngisd.org/gisd/speciesname/Acacia%20farnesiana).

⁶⁸ "Black Wattle." Invasive Plant Atlas of the United States. Accessed May 18, 2019. <https://www.invasiveplantatlas.org/subject.html?sub=5024>.

⁶⁹ "Trees." Trees: Invasive Plant Atlas of the United States. Accessed May 18, 2019. <https://www.invasiveplantatlas.org/trees.cfm>.

commonly found inland.⁷⁰ Many species are better able to establish themselves in disturbed areas.

E. Ecological Impact

Acacia species have demonstrated the ability to outcompete native plants. The combination of growth height and development of a large crown can cause neighboring plants to be shaded, impeding growth, while there is some evidence that particular *Acacia* species have alleopathic leaves or branches (meaning they are able to chemically hinder the growth of other nearby plant species).⁶⁴ Spread of *Acacia mearnsii* in Hawaii has led to replacement of native grass communities and loss of biodiversity.⁷¹

Acacia species' physiology can cause changes to local hydrology by increasing rainfall interception and decreasing runoff, resulting in lower flow rates in proximate streams.⁶⁴ They may also lead to the collapse of streambanks, as they do not physically support the soil to the degree that native species do in some areas. Additionally, some *Acacia* species have been found to make soil more prone to desiccation, and their nitrogen-fixing properties can alter chemical and pH qualities of soil.

International research has found that *Acacia* species' ability to accumulate large seed banks, combined with these seeds' longevity and disturbance-induced germination, can cause sudden ecological transformation and takeover in the wake of a disturbing event.⁷²

F. Human Health Impact

At the time of this report, no information has been found noting human health impacts of *Acacia* species, or lack thereof.

G. Economic Cost

International studies, particularly in Africa, have shown that spread of invasive *Acacia* species can have significant economic impacts. In some cases, economic impacts valued

⁷⁰ "Plant Search - Acacia." Calflora. Accessed May 18, 2019. <https://www.calflora.org/cgi-bin/specieslist.cgi?namesoup=acacia&countylist=any&plantcomm=any&format=photos&orderby=taxon>.

⁷¹ "Black Wattle (*Acacia Mearnsii*)." Hawaii Invasive Species Council. December 20, 2017. Accessed May 18, 2019. <https://dlnr.hawaii.gov/hisc/info/invasive-species-profiles/black-wattle-acacia-mearnsii/>.

⁷² Maitre, David C. Le, Mirijam Gaertner, Elizabete Marchante, Emilie-Jane Ens, Patricia M. Holmes, Anibal Pauchard, Patrick J. O'Farrell, Andrew M. Rogers, Ryan Blanchard, James Blignaut, and David M. Richardson. "Impacts of Invasive Australian Acacias: Implications for Management and Restoration." *Diversity and Distributions* 17, no. 5 (2011): 1015-029. doi:10.1111/j.1472-4642.2011.00816.x.

in the millions of dollars manifest as a result of *Acacia*'s hydrology-altering effects.⁶⁴ In other cases, encroachment by invasive *Acacia* plants can threaten agricultural or grazing land.⁷³

H. Best Management Practices

Many of the most effective proven management techniques for invasive *Acacia* species focus on responsible utilization practices, biological controls, public education, and global or regional strategies.⁷⁴ Many promising ongoing projects are being implemented in South Africa.⁶⁴

In the interest of preventing new introductions of invasive *Acacia* species, public education and awareness programs focused on the negative impacts of the plants may help reduce their use and accidental introduction. Additionally, providing information guidelines for commercial distributors and buyers of *Acacia* species may help lower the risk of careless introduction. A component of such a program should be discouraging the use of known high-risk invasive *Acacia* species in areas where they are not yet introduced.

Practices that may also help prevent spread of invasive *Acacia* plants include land management practices that make native landscapes more resilient to establishment and the use of surveys and assessments to promptly identify *Acacia* plants.⁷⁴ Research on what constitutes an effective detection program is still ongoing, but the propensity of *Acacia* plants to colonize disturbed habitats logically makes habitat resilience a priority.

For areas where invasive *Acacia* species have already been introduced or established, research suggests that total eradication should be the goal of population control programs.⁷⁴ Many established control practices focus on biological methods, especially insect species that predate on *Acacia* plants or seeds. Potential candidates include *Acacia* Seed Weevils and other weevil species; and chalcid wasps that parasitize *Acacia* plants.⁷⁴ Introduction of biological controls in California may be controversial, however, and requires careful evaluation of potential ecological ramifications.

Acacia species can also be manually removed, a practice which should be accompanied by habitat restoration projects to prevent reestablishment.⁷⁴ This may be a difficult process for some species, however (e.g. Blackwood acacia), as root fragments can resprout, necessitating complete removal of the root systems of mature plants.⁶¹

⁷³ Bufebo B, Elias E (2018) Distribution and Socio-economic Impacts of Invasive Alien Plant Species in Ethiopia: A Review. *Open J Plant Sci* 3(1): 026-033. DOI: [10.17352/ojps.000012](https://doi.org/10.17352/ojps.000012)

⁷⁴ Wilson, John & Gairifo, Carla & Gibson, Michelle & Arianoutsou, Margarita & B. Bakar, Baki & Baret, Stéphane & Celesti-Gradow, Laura & M. DiTomaso, Joseph & Dufour-Dror, Jean-Marc & Kueffer, Christoph & A. Kull, Christian & H. Hoffmann, John & A. C. Impson, Fiona & Loope, Lloyd & Marchante, Elizabete & Marchante, Hélia & Moore, Joslin & Murphy, Daniel & Tassin, Jacques & Richardson, David. (2012). Wilson et al 2011 DD acacia management.

Geraldton Carnation Weed – *Euphorbia Terracina*

A. Life History

Geraldton carnation weed (*Euphorbia terracina*) is an invasive perennial herb.⁷⁵ It is relatively short-lived, flowering in spring and subsequently losing most of its leaves during the summer.⁷⁶ This pattern may vary depending on local climatic conditions. In many individuals, stems die off concurrently with leaf loss, leaving behind a plant base that produces new stems in autumn.

Reproduction is facilitated by a variety of insect pollinators, and the plants are capable of self-breeding. Seeds are dispersed by explosive opening of plant fruits, which scatter the seeds in the area around an individual. Some ant species gather the seeds, producing clumps of the weed once germination occurs. Seeds from the weed can remain viable for several years.

Geraldton carnation weed produces a toxic sap found in both its leaves and stem, which discourage herbivory and grazing. The sap also reduces water loss from the plants.

a. Identification

Geraldton carnation weed grows up to 1 meter tall, with slim stems that are usually green or reddish and do not branch towards their base.⁷⁶ Leaves are offset and bright green, measuring between 1.5 and 4 cm long. Its root structure consists of many lateral roots branching horizontally from a large, central taproot. The weed's flowers are green and cup-shaped, and contain both female and male organs.

The weed's fruits resemble a three-part pod, with each lobe appearing smooth, measuring between 3 and 5 mm long. Seeds are about 2 mm long, smooth, and roughly oval-shaped with an auricle (an ear-like growth) at one end.

⁷⁵ Bettink, K. "Geraldton Carnation Weed *Euphorbia terracina* - Draft strategic plan for the Swan NRM Region." Australia Department of Environment and Conservation. December 2009.
https://www.dpaw.wa.gov.au/images/documents/conservation-management/off-road-conservation/urban-nature/reports/euphorbia_terr_strategic_plan_draft_dec_2009.pdf

⁷⁶ Keighery, Greg and Bronwen Keighery (2007). In; Proceedings of the Geraldton Carnation Weed (*Euphorbia terracina*) Workshop and Field Day, 21st June 2007. A Skills for Nature Conservation workshop organised by the Urban Nature Program of the Department of Environment and Conservation, Perth. Held at the Naragebup Rockingham Regional Environment Centre, Peron, Western Australia.

B. Origin

Geraldton carnation weed is native to the Mediterranean region, both the coastal areas (e.g. Italy) and several islands, with the range reaching as far northeast as the Black Sea.⁷⁷ Its scientific name *Euphorbia terracina* is derived from the coastal Italian town Terracina, while its common name refers to the Geraldton region of Australia, where it has seen significant growth.⁷⁶ Specific areas considered within the weed's native range include countries in northern Africa (e.g. Algeria, Egypt, Morocco, Tunisia), the Middle East (e.g. Israel, Jordan, Syria, Turkey), and Europe (e.g. Albania, France, Greece, Italy, Portugal, Spain), as well as Yugoslavia.⁷⁸

C. Current Global/National Spread

Outside of its native range, Geraldton carnation weed has been identified in various coastal regions of western Australia, Mexico, and the United States.⁷⁸ Within the United States it has been found in southern California and possibly Pennsylvania (some inconsistent information has been found regarding the latter).^{79 80}

D. Distribution in Los Angeles County

Most observations of Geraldton carnation weed in Los Angeles County are concentrated along the coasts, particularly in the Palos Verdes Peninsula area and north of Santa Monica.⁷⁹ There have also been some observations further inland in the areas between Santa Clarita and San Fernando and the Angeles National Forest.

E. Ecological Impact

Geraldton carnation weed can spread quickly thanks to its virulent reproductive strategy (producing large numbers of non-dormant seeds), and it has demonstrated the ability to overgrow and outcompete many native herb and grass species.⁷⁷ In some areas this has caused complete replacement of native flora, creating monoculture patches of the weed. This may have secondary consequences for grazing fauna, given the weed's undesirable nature as a target for herbivory.

Since its introduction to California, the weed has been spreading "at a virtually

⁷⁷ "Geraldton Carnation Weed (Euphorbia Terracina)." VRO. Accessed May 19, 2019. http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/weeds_geraldton-carnation-weed.

⁷⁸ Reichard, Sarah and Lizbeth Seebacher. "Weed Risk Assessment for *Euphorbia terracina* L." United States Department of Agriculture APHIS. February 22, 2009.

https://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/wra/EuphorbiaterracinaWRA.pdf

⁷⁹ "Euphorbia Terracina." Calflora. Accessed May 19, 2019. https://www.calflora.org/cgi-bin/species_query.cgi?where-calrecnum=8565.

⁸⁰ "Euphorbia Terracina L." USDA Natural Resources Conservation Service. Accessed May 19, 2019. <https://plants.usda.gov/core/profile?symbol=EUTE10>.

exponential rate” along coastal areas, and has demonstrated a significant ability to become well-established in disturbed areas.⁸¹ Research outside of the United States on ecologically similar species has shown the potential for creation of dense mats, indicating the risk of significant shifts in invaded coastal sage scrub habitats in California.⁸²

F. Human Health Impact

The milky sap in Geraldton carnation weed leaves and stalks, in addition to discouraging herbivory, can cause injuries in humans if exposure occurs. These can include inflammations, temporary blindness, and permanent vision loss.⁸³

G. Economic Cost

There is mixed information on the costs that infestation by the weed imposes on agriculture, much of which comes from Australia. Some studies have concluded that it does not have any appreciable impact on agriculture crop quality, while others note it as a serious pest.⁷⁷ Slight cost increases associated with harvest procedures may occur in areas where the weed proliferates. Control and management procedures may have associated costs; some local governments in Australia have incurred costs ranging from \$30,000 to \$75,000 annually (Australian dollars, US equivalent: \$20,700 to \$51,750) on pest control for the plant.

H. Best Management Practices

Some trials of chemical herbicides have shown promising results in combatting Geraldton carnation weed. Triasulfuron (brand name Logran) has been shown, when used at a concentration of 12.5 g per 100 L, to decrease weed coverage while allowing native flora to regrow.⁸⁴ Glyphosate (RoundUp) has also been used to remove the weed in the United States, but its broad-spectrum nature makes it more suitable for areas where the weed has achieved complete or near-complete coverage.

⁸¹ Riordan, Erin C., Philip W. Rundel, Christy Brigham, and John Tiszler. "Morphological Traits and Invasive Potential of the Alien *Euphorbia Terracina* (Euphorbiaceae) in Coastal Southern California." *Madroño* 55, no. 1 (January 1, 2008): 52-59. doi:10.3120/0024-9637(2008)55[52:mtaipo]2.0.co;2.

⁸² Andreu, J., E. Manzano-Piedras, I. Bartomeus, E. D. Dana, and M. Vila. "Vegetation Response after Removal of the Invasive *Carpobrotus* Hybrid Complex in Andalusia, Spain." *Ecological Restoration* 28, no. 4 (2010): 440-48. doi:10.3368/er.28.4.440.

⁸³ Randall, R. & Brooks, K 2000, Managing Weeds In Bushland- Geraldton Carnation Weed, Environmental Weeds Action Network (EWAN), West Perth.

⁸⁴ Brown, Kate and Julia Cullity. (2007) In; Proceedings of the Geraldton Carnation Weed (*Euphorbia terracina*) Workshop and Field Day, 21st June 2007. A Skills for Nature Conservation workshop organised by the Urban Nature Program of the Department of Environment and Conservation, Perth. Held at the Naragebup Rockingham Regional Environment Centre, Peron, Western Australia.

Physical removal and control of the weed is difficult, requiring removal of the root systems to prevent resprouting. Post-disturbance procedures (especially following fire events) to remove the plant can help avoid takeover, as there is a tendency for the weed to resprout stems and rapidly overgrow areas cleared by recent fires and other disturbing events.⁸⁴

Given the weed's propensity to colonize disturbed areas, land management practices that maintain resilient native habitat may help avoid initial establishment.

Sweet Fennel – *Foeniculum vulgare* (Plant)

A. Life History

Foeniculum vulgare, commonly known as fennel, common fennel anise, sweet fennel, aniseed, or sweet anise, is a perennial herb found in many regions of California.⁸⁵ It can germinate more or less year-round, but annual growth begins in the winter and reaches its maximum in later summer (July-August). Plants typically reach sexual maturity between a year-and-a-half and two years after germination.

Flowering usually occurs in late spring (e.g. early May), though flowering stems begin growing as early as late winter.⁸⁵ Seeds are produced at similar times of year, usually peaking in late summer or early autumn (e.g. August-September). Seeds can be spread via various means, including water and human/animal activity. Fennel can also reproduce via fragmentation of its root crown.⁸⁶

Fennel prefers Mediterranean climate conditions, mostly being found in sites that have access to water (both fresh or brackish) below 2,000 feet of elevation.⁸⁵ It can also colonize areas with high levels of disturbance (e.g. roadsides, damaged habitat) and open areas (e.g. grasslands, coastal sage scrub, riparian areas near bodies of water). Once established, it can create densely populated strands within a given area.⁸⁶

a. Identification

At full growth, a single fennel plant will exhibit a large group of stems (10-20) between four and ten feet tall, emanating from a cluster connected to the plant's large central taproot.⁸⁵ Stems are usually have solid green coloration with petioles 2.8-5.6 inches long sheathing the them, and will die off in autumn (September to

⁸⁵ "IPCW Plant Report." California Invasive Plant Council. December 27, 2017. Accessed May 22, 2019. <https://www.cal-ipc.org/resources/library/publications/ipcw/report51/>.

⁸⁶ "Common Fennel." Washington State Noxious Weed Control Board. Accessed May 22, 2019. <https://www.nwcb.wa.gov/weeds/common-fennel>.

November).

Leaves resemble thread-like netting, their overall shape being triangular-ovate and measuring up to two feet long and over one foot wide. Flowers appear in flat-topped umbels (flower clusters) and have yellow petals, with the inflorescence (complete flower head) measuring 0.4-1.6 inches. Flower petal tips narrow towards the end, and contain five stamens and two styles.

Fennel plants have a characteristic sweet smell resembling that of black licorice.⁸⁷ The fruits of wild plants are ovoid, usually between 3-5 mm long and 1.5-2 mm wide, with blunt ends and dark coloration.⁸⁸

B. Origin

Fennel originated in the Mediterranean area, including southern Europe.⁸⁵ It has historically been cultivated for human uses. It was introduced to California over a century ago, though its introduction has not been attributed unequivocally to a certain mechanism.

C. Current Global/National Spread

Detailed information on the global distribution of fennel has been difficult to identify at the time of this report. However, information on vernacular regional terms for the plant may be a valid proxy, and as such the plant can be identified in multiple global regions, including Europe, South and East Asia (e.g. Korea, India, Japan, Indonesia), the Middle East (e.g. Jordan, Pakistan), Central and South America (e.g. Mexico, Ecuador, Brazil), and the United States.⁸⁸

Within the United States the plant's distribution is concentrated in California, though it has also been identified to a lesser extent in Washington state and Oregon, and rarely in North Carolina and the New England area.⁸⁹

D. Distribution in Los Angeles County

The highest numbers of observations of fennel in Los Angeles County occur along the coast, especially in the Palos Verdes Peninsula and Santa Monica areas.⁸⁹ There are also

⁸⁷ "Common Fennel." Coastal Invasive Species Committee. Accessed May 26, 2019. <https://www.coastalisc.com/Priority-Invasive-Plants/common-fennel.html>.

⁸⁸ Badgujar, Shamkant B., Vainav V. Patel, Atmaram H. Bandivdekar. "Foeniculum vulgare Mill: A Review of Its Botany, Phytochemistry, Pharmacology, Contemporary Application, and Toxicology." *Biomed Research International* 2014 (2014): 842674. Doi: [10.1155/2014/842674](https://doi.org/10.1155/2014/842674)

⁸⁹ EDDMapS. 2019. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at <http://www.eddmaps.org/>; last accessed May 26, 2019.

notable hot spots for observation numbers in the areas north of Inglewood and around La Habra Heights. Numerous observations have also been documented inland, including around Glendale, Pasadena, and the Angeles National Forest.⁹⁰ Overall, fennel can be characterized as ubiquitous within Los Angeles County.

E. Ecological Impact

Fennel has been found to have a significant detrimental impact on native plant species. It may have alleopathic properties, chemically inhibiting the growth of competing plants.⁸⁵ Its dense growth patterns, tall stems, rapid reproduction allow it to shade and outcompete many native plant species. In some cases this can lead to near-complete replacement of native species, with fennel strands achieving between 50% and 90% coverage.⁸⁵ Its reproductive strategy also leads to the quick development of a large seed bank.

Secondary effects of fennel transforming native ecosystems by outcompeting native plants are less clear-cut. In the course of research for this report, no information has been found establishing changes to soil or hydrology resulting from native plant displacement by fennel, though one could reasonably assume that fennel's dense colonization patterns may cause disruptions. Similarly, effects of fennel colonization on animals is relatively unknown. Grazing species have been found to consume fennel during its early growth stages, though more mature plants are not a common target of herbivory.⁸⁵ Smaller animals, such as birds and rodents, have been found to consume fennel seeds, and feral pigs will eat fennel roots. There is also evidence that fennel can change insect composition in invaded areas by hosting mutualistic argentine ants (*Linepithema humile*) and several aphid species.⁹¹

F. Human Health Impact

Fennel is widely used globally for treating a variety of ailments and afflictions in traditional medicine practices.⁸⁸ Several such uses have been backed up with empirical research, showing that extractions from fennel can be used as an anti-inflammatory, to counteract certain toxins, and as an anti-anxiety medication, among others.

In the course of reviewing materials for this report, no information was found regarding direct negative impacts of fennel on human health.

⁹⁰ Calflora: Information on California plants for education, research and conservation, with data contributed by public and private institutions and individuals, including the Consortium of California Herbaria.[web application]. 2019. Berkeley, California: The Calflora Database [a non-profit organization]. Available: <https://www.calflora.org/> (Accessed: May 26, 2019).

⁹¹ Dibble, Connor D. "Ecological Effects of Ant-aphid Mutualism on the Invasive Potential of *Foeniculum vulgare* in Northern California Coastal Scrub." May 11, 2009. University of California, Berkeley College of Natural Resources. https://nature.berkeley.edu/classes/es196/projects/2009final/Dibble_2009.pdf

G. Economic Cost

Fennel is cultivated at a small scale in the United States, with 40% of the country's crop being produced in California as of 2000.⁹² The value of these crops is millions of dollars; Monterey county's crop of nearly 500 acres was worth \$3.2 million in 1998. However, more current data is lacking, and Los Angeles County has not been a site of fennel production, historically.

Control and management of invasive fennel require funds from municipalities and state agencies, both for supplies (e.g. herbicide) and labor. However, at the time of this report, exact figures on funds allocated by California or counties therein specifically for fennel control have not been found.

H. Best Management Practices

Fennel spread can be managed by both chemical and non-chemical methods. In areas of light coverage, manual removal can be effective, and includes measures such as plowing, bulldozing, or digging plants out by hand.^{85 93} These methods are the most consistently effective, as they remove the plants' root systems and thereby prevent regrowth. However, plowing and bulldozing can cause significant soil disturbance and hand removal is time- and labor-intensive.

Chopping or slashing can be effective in cases of light infestation before the plants flower, which may kill individual plants.⁸⁷ Continuing to cut regrowing plants may prevent seed dispersal. However, generally, physical measures like slashing and mowing that fail to remove roots are not consistently effective. In conjunction with other measures, prescribed burning may be effective at clearing areas for restoration.⁹⁴

Herbicides have been found to be effective at controlling fennel and significantly decreasing area coverage, independent of whether other measures were used concurrently.⁹⁴ Glyphosate (RoundUp) and triclopyr, used independently at rates of at least 2 lb/acre or 1 lb/acre, respectively, or in concert, were found to significantly reduce fennel coverage at both the six week and one year time-frames.⁹⁵ Broadcast treatments have been found to be more time-efficient and effective at controlling densely infested areas, but may be inappropriate in areas with sparser infestations.

⁹² Kurtz, Edward A. and Ed Mora. "Crop Profile for Fennel in California." September 2000. USDA NIFA. <https://ipmdata.ipmcenters.org/documents/cropprofiles/CAfennel.pdf>

⁹³ Gwinn, Abigail, "The cost and effectiveness of small-scale control methods on fennel, *Foeniculum vulgare*, in Natividad Creek Park, Salinas, CA" (2007). Capstone Projects and Theses. Paper 50.

⁹⁴ Brenton, R. K. and R.C. Klinger (2002). "Factors influencing the control of fennel (*Foeniculum vulgare* Miller) using triclopyr on Santa Cruz Island, California, USA." *Natural Areas Journal* 2 (22), 135-147.

⁹⁵ Bell, Carl E., Todd Easley, and Kari Roesch Goodman. "Effective Fennel (*Foeniculum Vulgare*) Control with Herbicides in Natural Habitats in California." *Invasive Plant Science and Management* 1, no. 1 (2008): 66-72. doi:10.1614/ipsm-07-002.1.

There are no known biological control agents for fennel.⁹⁶ Grazing has been shown to be ineffective, and cattle may spread fennel seeds during flowering season.⁸⁵

Garland Daisy (*Glebionis coronaria*) - Plant

A. Life History

Garland daisy (*Glebionis coronaria*), also known as garland chrysanthemum and crown daisy, is an annual flowering plant that has historically been used for ornamental purposes.⁹⁷ When cultivated, plants typically germinate in approximately fourteen days after time of planting; information on germination timeline in wild specimens is scant.⁹⁸ Once sufficient moisture is present (i.e. shortly after rainfall), seeds will sprout quickly.

Flowers bloom from midsummer to fall.⁹⁸ Individual plants produce fruits prolifically, numbering in the thousands, and as such can generate large numbers of seeds for subsequent years.⁹⁹ This can cause the formation of densely populated strands of daisies, often in conjunction with other species like poison hemlock (*Conium maculatum*) and fennel (*Foeniculum vulgare*). Plants are hermaphroditic and capable of self-fertilization.¹⁰⁰ After death, plant biomass can persist in a colonized area for years.⁹⁷

a. Identification

Garland daisies are most commonly found in disturbed areas, with a general preference for coastal, riparian, and grassland habitats.¹⁰¹ Plants have a single, tough stem with branching, lobed leaves.⁹⁹ Leaves may have a toothed appearance and are green in color, usually less than eight centimeters long.¹⁰² When fully grown, plants can reach four to five feet in height.⁹⁷

⁹⁶ DiTomaso, J.M., G.B. Kyser et al. 2013. *Weed Control in Natural Areas in the Western United States*. Weed Research and Information Center, University of California. 544 pp.

⁹⁷ "Glebionis Coronaria Profile." California Invasive Plant Council. March 15, 2018. Accessed May 28, 2019. <https://www.cal-ipc.org/plants/profile/chrysanthemum-coronarum-profile/>.

⁹⁸ "Garland Daisy Seeds - Chrysanthemum Coronarium." EdenBrothers.com. Accessed May 28, 2019. https://www.edenbrothers.com/store/garland_daisy_seeds.html.

⁹⁹ Prigge, B.A. and A.C. Gibson. "Glebionus coronaria." Accessed online May 27, 2019. https://www.smmflowers.org/bloom/PDF-species/Glebionis_coronaria_UCLA_SantaMonicas.pdf

¹⁰⁰ "Chrysanthemum coronarium – L." <https://pfaf.org>. Accessed May 27, 2019. <https://pfaf.org/user/plant.aspx?LatinName=Chrysanthemum+coronarum>

¹⁰¹ "San Diego County Invasive Ornamental Plant Guide." San Diego Chapter of the American Society of Landscape Architects & California Native Plant Society. October 3, 2005. Accessed online May 27, 2019. https://www.asla-sandiego.org/aslasdwp/wp-content/uploads/2014/10/Most_Invasive_Plant_Guide.pdf

¹⁰² "Glebionis Coronaria." The Jepson Herbarium. Accessed May 28, 2019. http://ucjeps.berkeley.edu/eflora/eflora_display.php?tid=81846.

The inflorescence (flower head) of garland daisies measures between two and six centimeters in diameter.¹⁰² The disk flower (central portion of the flower) has a corolla 4-5 mm in diameter, with the ray flower (full flower) being 6-12 mm in diameter.^{99 102} Flower rays are yellow or cream-colored, while disk is yellow above and whitish-colored below.

Garland daisies possess a large taproot.⁹⁹ Fruits are asymmetrical and wedge-shaped, with several ribs and wing. The fruits are usually brown in color.

B. Origin

Garland daisies are considered native to the Mediterranean and portions of East Asia.¹⁰³ They have been cultivated for consumption and widely used as ornamental plants, the latter use having contributed to their introduction to non-native areas when it has spread outside of intended areas.

C. Current Global/National Spread

At the time of this report, specific country-level information on global distribution of garland daisies is scant. It is established in its native Mediterranean and East Asia regions, including territories like Italy and Crete.¹⁰⁴ Its presence in culinary practices in several Asian territories (e.g. China, Hong Kong, Taiwan, Korea) implies a likelihood of cultivation in those countries or proximate areas. The plants are also found in several areas of the United States and some regions of Canada (e.g. Great Lakes area).¹⁰⁵

Within the United States, garland daisies are found in Maine, Vermont, Massachusetts, Alabama, Florida, Colorado, Arizona, and California.¹⁰⁵

D. Distribution in Los Angeles County

Within Los Angeles County, most observations of garland daisies are clustered along the coastal areas, especially in the vicinity of the Palos Verdes Peninsula.¹⁰⁶ There have also

¹⁰³ "Garland Daisy (Invasive Species of Crest Canyon) · INaturalist.org." INaturalist.org. Accessed May 28, 2019. https://www.inaturalist.org/guide_taxa/660307.

¹⁰⁴ "Chrysanthemum Coronarium Invasive Plant Information." Chrysanthemum Coronarium Invasive Plant Facts and Images. Accessed May 28, 2019. <http://www.badplants.com/show/plant/Chrysanthemum-Coronarium/707>.

¹⁰⁵ "Plants Profile for Glebionis Coronarium (crowndaisy)." USDA Natural Resources Conservation Service. Accessed May 28, 2019. <https://plants.usda.gov/core/profile?symbol=GLCO6>.

¹⁰⁶ [Calflora](#): Information on California plants for education, research and conservation, with data contributed by public and private institutions and individuals, including the [Consortium of California Herbaria](#). [web application].

been some observations inland, in the Angeles National Forest area.

E. Ecological Impact

Garland daisy's ecological impact largely result from its detrimental impact on native plant species. Its prolific reproduction strategy allows it to quickly populate a newly colonized area, especially if that area is already disturbed. Garland daisies can grow in dense monocultures, preventing native species from competing for resources, and their height may let them shade out lower-growing plants. There is speculation that garland daisy growth may disrupt the behavior of wildlife that prefer open areas.

In subsequent years, dead garland daisy plants' biomass can remain in place for prolonged periods of time, up to multiple years. This detritus can prevent native species from recolonizing an area without concerted restoration efforts.

F. Human Health Impact

In the writing of this report, no information on garland daisy's direct human health impacts has been identified. The plant is cultivated for consumption in some regions, which may make it a vector for contaminants.

G. Economic Cost

Information on the economics of invasive garland daisies is scant. The plant is a popular ornamental, with seeds and live plants sold online and at nurseries. However, at the time of this report, no quantitative information on the size of the garland daisy market has been found. Similarly, no specific information on the cost of managing invasive garland daisies has been found.

H. Best Management Practices

There is a startling lack of specific information currently available on best practices for control and management of invasive garland daisies. In the writing of this report, reviewing numerous profiles and listings of the species from independent entities, university institutions, and state and federal agencies, none provided specific guidelines detailing removal procedures, effective herbicidal treatments, or other control methods. At this time, it seems advisable to test responses that are effective for other taxonomically or ecologically similar noxious weeds.

Castor Bean – *Ricinus communis* (Plant)

A. Life History

Castor bean, *Ricinus communis*, is a perennial shrub most commonly found in coastal and riparian areas.¹⁰⁷ It is an herbaceous plant when young, but older individuals can become woody, resembling small evergreen trees. In temperate areas like the United States its growing period is longer than in tropical regions, that longer period being 140-180 days.¹⁰⁸ This makes its growth pattern in the United States closer to that of an annual plant.

Castor bean plants are fast-growing--capable of growing 2-5 meters in one growing season under optimal conditions--and reach sexual maturity in approximately six months, after which they can flower year-round in frost-free areas.¹⁰⁹ Seed production varies wildly based on plants' size, with small individuals shown to produce approximately 1,500 seeds while very large specimens have been found producing up to 150,000 seeds.

Germination process for seeds is slow—between 10-21 days after planting when cultivated—and typically occurs between December and April.^{108,109} However, variation in environmental factors (e.g. weather) can cause germination to occur outside of this time of year.

a. Identification

When fully grown, castor bean plants can be between 1 and 5 meters (3.3 and 16.4 feet) tall.¹¹⁰ The plants' stems are red in color, round in shape, and smooth in texture.

It has large leaves that measure 10-75 cm across with between 5 and 11 pointed lobes, which may appear serrated at the edges.^{107 109} Leaves are typically deep green in color, though some may have tones of red. When crushed, leaves exude a notable odor. Leaf attachment alternates on the stem and leaves are peltate (stem is attached on the underside of the leaf, as opposed to along the edge, as is more common).

¹⁰⁷ "Ricinus Communis." GISD. Accessed June 02, 2019.

<http://www.iucngisd.org/gisd/species.php?sc=1000>.

¹⁰⁸ "Castor Bean." Corn Agronomy. Accessed June 02, 2019.

<http://corn.agronomy.wisc.edu/Crops/CastorBean.aspx>.

¹⁰⁹ "IPCW Plant Report." California Invasive Plant Council. October 16, 2017. Accessed June 03, 2019. <https://www.cal-ipc.org/resources/library/publications/ipcw/report69/>.

¹¹⁰ "Castorbean." Invasive Plant Atlas of the United States. Accessed June 03, 2019. <https://www.invasiveplantatlas.org/subject.html?sub=6320>.

Flowers are small, green, and unisex—flowers contain either many yellow, male stamens or three female styles, which are red in color.¹⁰⁹ The inflorescence (flower head) measures 4-12 inches in length. Castor bean flowers do not have petals, nectaries, or disks. Plants are monoecious (flowers of both sexes appear on the same plant), and flowers are usually clustered along a terminal spike, with male flowers on the lower portion and female flowers on the upper part.¹⁰⁷

Castor bean fruits (the titular "bean"—the plant is not, in fact, leguminous) are green-colored, grooved capsules that measure up to 2.5 cm in length. Each fruit has three carpels (flowering plant reproductive organ), which each contain one seed. The fruits are covered in soft spines and may be green or pink when developing, eventually turning brown as they ripen and split to release their seeds.¹¹¹ Seeds measure 3-4 mm wide and 9-22 mm long and are usually shiny and silver in appearance.¹⁰⁹

B. Origin

Castor bean's native regions are considered to include the warm regions of Asia and Africa.¹⁰⁹ Specific regions and countries include Southwest Asia (e.g. Afghanistan, Pakistan), the Middle East (e.g. Iran, Israel, Jordan, Turkey), Africa (e.g. Algeria, Angola, Morocco, South Africa) and Europe (e.g. Hungary).¹⁰⁷

C. Current Global/National Spread

Castor bean has spread globally, and is found on every continent except Antarctica.¹¹² This is partially due to historic cultivation for harvesting oil and for ornamental use.¹⁰⁹

Countries where castor bean is known to be present and nonnative within general global regions include: Asia (e.g. Cambodia, China, India, Korea, Malaysia), Oceania (e.g. Australia, New Zealand, numerous Pacific Island groups), North America (e.g. Canada, United States, Mexico), the Caribbean (e.g. Bermuda, Bahamas, Cuba, numerous other Caribbean islands), Central America (e.g. Belize, Costa Rica), South America (e.g. Argentina, Brazil, Venezuela, Chile, Colombia), and Europe (e.g. Austria, Greece, Italy, France, Spain, UK, some former Eastern Bloc countries).¹¹²

Within the United States, Castor bean has been identified in numerous states, mostly in the New England, South, and Southwest regions.¹¹³ Within these respective regions, the

¹¹¹ Susan.mahr. "Castor Bean, Ricinus Communis." Master Gardener Program. Accessed June 05, 2019. <https://wimastergardener.org/article/castor-bean-ricinus-communis/>.

¹¹² "Ricinus Communis (castor Bean)." CABI Invasive Species Compendium. Accessed June 05, 2019. <https://www.cabi.org/isc/datasheet/47618>.

¹¹³ "Ricinus Communis L. (castorbean)." USDA Natural Resources Conservation Service. Accessed June 05, 2019. <https://plants.usda.gov/core/profile?symbol=RICO3>.

plant has been observed in every New England state except Maine and Vermont; a contiguous swath of the coastal southern states from Virginia to Texas, as well as Tennessee; and California, New Mexico, and Utah. It has also been found in some midwestern and northern states, including Missouri, Kansas, Illinois, Ohio, Michigan, and Mississippi.¹¹² Outside of the continental United States, castor bean has been found in Hawaii.

D. Distribution in Los Angeles County

A significant majority of observations of castor bean in California have been made in Southern California, particularly in coastal regions from Santa Barbara County south to San Diego County.¹¹⁴ Within LA County the highest concentrations of observations are along the coast, especially the Santa Monica and Palos Verdes Peninsula areas. However, observations of the plant are common throughout the southern half of the county, extending as far inland as San Fernando and the Angeles National Forest.

E. Ecological Impact

The most notable direct ecological impact of castor bean is the displacement of native plant species. Displacement most often occurs in areas with water—drainages and riparian areas.^{107 109} Castor bean's fast growth rate and height allow it to overgrow and shade out many other types of plants, especially native seeds and seedlings. This can be especially problematic post-fire events, when castor bean seeds germinate quickly. Disturbed areas can come to be dominated by castor bean monocultures.

Castor bean is also highly toxic, and has been linked to the deaths of some wild species (e.g. ducks).¹⁰⁹ Consumption of a small number of the plant's beans can kill even large animals. Some herbivorous insects (e.g. aphids) can be killed after ingesting castor bean plant tissue, and some soil-dwelling organisms (e.g. nematodes) have been found to experience population decreases when castor bean plants are prolific.

F. Human Health Impact

Castor bean plants produce ricin, one of the most lethal toxic substances in existence, being 6,000 times more toxic than cyanide on a gram-for-gram basis.¹¹⁵ Ricin concentrations are highest in castor bean seeds, though some is also found in other plant tissues, such as its leaves.¹⁰⁹ Consuming as few as 2-4 seeds can be lethal for an average human adult, though the seed coating needs to be damaged (such as through chewing) for

¹¹⁴ [Calflora](https://www.calflora.org/): Information on California plants for education, research and conservation, with data contributed by public and private institutions and individuals, including the Consortium of California Herbaria.[web application]. 2019. Berkeley, California: The Calflora Database [a non-profit organization]. Available: <https://www.calflora.org/> (Accessed: Jun 05, 2019).

¹¹⁵ "The Castor Bean." Castor Bean Plant. Accessed June 05, 2019. <https://www2.palomar.edu/users/warmstrong/plmar99.htm>.

poisoning to occur.^{109 111}

Castor bean has been linked to allergic reactions, including in cases where castor oil is consumed and where farm workers have been exposed to castor beans and dust.¹⁰⁹ In the latter cases, which occurred in Brazil and India, individuals experienced allergy-related asthma and anaphylaxis.

G. Economic Cost

While castor beans are cultivated for castor oil, the United States is not a major producer of castor oil.¹¹⁶ Some cultivation of castor bean does take place in California, but figures on the economic impact of this industry have not been found at the time of this report.¹¹⁷ It does constitute a major importer, as castor oil has numerous industrial and commercial uses, but specific information on the magnitude of this market is lacking.

Similarly, figures on the cost of expenditures for castor bean control and the incidence of castor bean poisoning (and related medical expenditures) are lacking. With regards to the latter, most records found in the course of this report are anecdotal case studies, without broader records.^{118 119}

H. Best Management Practices

Castor bean can be controlled via both physical and chemical methods, depending on specific circumstances. Physical removal by hand (which should be done with gloves) is effective when plants are small enough or present in sufficiently moist soil that the entire root can be removed.¹⁰⁹ Remnants of castor bean root crowns can regrow multiple stems, and as such any mechanical removal methods must address the root systems.

Application of chemical herbicides (e.g. sprayed 2% glyphosate, commercially known as RoundUp) is effective at controlling fully-grown castor bean plants, but is non-specific and can have detrimental impacts on native flora. Plant-specific treatment with 25% glyphosate can also be effective in non-monocultured areas, where mechanical paring of the plant reduces it to a stump which is then sprayed with herbicide. There is also evidence that the herbicide Banvel is highly effective when used with the cut-stump treatment, and the Garlon 4 herbicide at 10% concentration has also been used

¹¹⁶ Patel, Vinay R., Gerard G. Dumancas, Lakshmi C. Kasi Viswanath, Randall Maples, and Bryan John J. Subong. "Castor Oil: Properties, Uses, and Optimization of Processing Parameters in Commercial Production." *Lipid Insights*9 (2016). doi:10.4137/lpi.s40233.

¹¹⁷ "Rivrlab.msi.ucsb.edu." Castor Bean. Accessed June 17, 2019.
<http://rivrlab.msi.ucsb.edu/invasive-species/castor-bean>.

¹¹⁸ AL-Tamimi, Faisal A., Ahmad EM Hegazi (2008). "A Case of Castor Bean Poisoning." *Sultan Qaboos University Medical Journal* 8(1): 83-87.

¹¹⁹ de Haan, P., L.M. Reidinga-Saenen, J.A. Korporaal-Heijman (2016). "Intoxication by ingestion of castor beans." *Netherlands Journal of Critical Care* 24(2): 20-22.

successfully.¹⁰⁷ Sites should be visited frequently following herbicide treatments to hand-remove seedlings.

Fire is not an effective mechanical removal method, as it often primes areas for colonization by other non-native plants. Likewise, grazing and other biological controls are either ineffective or nonexistent.

Eurasian Collared-Dove (*Streptopelia decaocto*)

A. Life History

The Eurasian collared-dove, *Streptopelia decaocto*, is a highly invasive bird related the Rock Pigeon *Columba livia* (i.e. the common pigeon), among other species.¹²⁰ They have proven well-adapted to urban and suburban areas, and are commonly found both these areas and some rural settings in most parts of the continental United States.¹²¹ The birds commonly feed upon grains (e.g. millet, sunflower, milo, wheat, corn), seeds, berries, and insects, as well as some other human-derived sources (e.g. bread crumbs) and organisms (e.g. snails).¹²² This leads to Eurasian collared-doves seeking out anthropogenic food sources such as grain silos and bird feeders. Outside of such sources, foraging behavior is usually done at ground level in flocks, except during breeding periods when flocking behavior is not exhibited. Such feeding flocks can be up to several hundred birds in size around popular locations. While intraspecific competition among Eurasian collared-doves while feeding is not typically observed, the birds will engage in confrontational behavior with other species.

Eurasian collared-doves may breed several times annually, raising three to six broods in a year.¹²³ Breeding is most common between February and October, but may occur year-round depending on location.¹²⁴ Breeding pairs are monogamous. The pair engages in a lengthy courtship ritual, which includes the male making attracting vocal calls and physical mating displays, leading a paired female to potential nesting sites (almost always at least 10 feet above the ground; e.g. large trees, buildings), mutual preening, and—upon approval of a nesting site—bringing the female material (usually twigs and sticks) with which she constructs a nest.¹²² The female lays 1-2 eggs (2 is common), which incubate in 14-19 days. During juvenile development in the nest, both parents produce "pigeon milk" or "crop milk" from esophageal cells as a regurgitant food source for 5-10 days before the chicks begin consuming a normal regurgitated diet.¹²¹ The total nesting period lasts 15-20 days, after which they may continue to be nurtured by their parents up to another week.¹²² Juveniles are usually completely independent within 30-40 days after hatching.¹²⁴ Occasionally the parental pair will begin a new brood before the previous

¹²⁰ "Eurasian Collared-Dove Identification." All About Birds, Cornell Lab of Ornithology. Accessed June 18, 2019. https://www.allaboutbirds.org/guide/Eurasian_Collared-Dove/id.

¹²¹ "Eurasian Collared-Dove Overview." All About Birds, Cornell Lab of Ornithology. Accessed June 18, 2019. https://www.allaboutbirds.org/guide/Eurasian_Collared-Dove/overview.

¹²² "Eurasian Collared-Dove." Audubon. March 21, 2019. Accessed June 18, 2019. <https://www.audubon.org/field-guide/bird/eurasian-collared-dove>.

¹²³ "Eurasian Collared-Dove Life History." All About Birds, Cornell Lab of Ornithology. Accessed June 18, 2019. https://www.allaboutbirds.org/guide/Eurasian_Collared-Dove/lifehistory.

¹²⁴ "Streptopelia Decaocto." GISD. Accessed June 18, 2019. <http://www.iucngisd.org/gisd/species.php?sc=1269>.

chicks have completed their nesting period.

Eurasian collared-doves usually reach sexual maturity at approximately one year old. Mortality during this first year has been measured at 50-70% in Europe.¹²⁴ Adult annual mortality drops to 33-55%. The oldest identified wild bird age is 17.8 years.¹²⁵

a. Identification

Individuals of both sexes usually measure 11.4-12.5 inches in length with a wingspan of approximately 13.8 inches and a weight between 4.9 and 6.3 ounces.^{120 126} Compared to Rock pigeons (common pigeons) they are thinner but have longer tails, which are squared at the tip.

Coloration is tan or sandy brown, with the head and undersided lighter than other parts of the body, while wingtips are darker. Bird bills are dark colored and a dark black crescent is visible on the back of the neck, from which the common name is derived.

Eggs are white and measure 1.1-1.2 inches in length, 0.8-0.9 inches in width.¹²³ The birds' nests resemble rickety platforms comprised of twigs and sticks.

B. Origin

Eurasian collared-doves' original range was the Bay of Bengal, proximate to India, Sri Lanka, and Myanmar.¹²⁷ In the 1930s the species' range was limited to Southwest Eurasia and some parts of the Middle East (e.g. Turkey, Syria, Iraq, Greece, Bulgaria).¹²⁸ It has naturally spread to numerous countries across Europe, Asia, and the Middle East, which are considered part of the species' native range. Countries where the species is considered native range from the United Kingdom and Ireland east to Russia and Korea and south to include many Mediterranean and Middle East nations (e.g. Italy, Jordan, Saudi Arabia) and north to some Scandinavian countries (e.g. Norway). It is also considered native in some island territories, including the Faroe Islands and Sri Lanka.

¹²⁵ "AnAge Entry for Streptopelia Decaocto." AnAge: The Animal Ageing and Longevity Database. Accessed June 18, 2019.

http://genomics.senescence.info/species/entry.php?species=Streptopelia_decaocto.

¹²⁶ "Eurasian Collared Dove." National Geographic. September 24, 2018. Accessed June 18, 2019. <https://www.nationalgeographic.com/animals/birds/e/eurasian-collared-dove/>.

¹²⁷ "Eurasian Collared Dove." Texas Invasive Species Institute. Accessed June 18, 2019. <http://www.tsusinvasives.org/home/database/streptopelia-decaocto>.

¹²⁸ "Streptopelia Decaocto." Issg Database: Ecology of Streptopelia Decaocto. Accessed June 18, 2019. <http://issg.org/database/species/ecology.asp?si=1269&fr=1&sts=&lang=EN>.

C. Current Global/National Spread

Outside of its aforementioned native range, Eurasian collared-doves have been introduced and spread by humans to several global areas. These include portions of Asia (e.g. Japan), Central America (e.g. Belize), North America (Mexico, the United States, and Canada) and numerous islands, mostly in the Caribbean (e.g. Antigua and Barbuda, Bahamas, Cayman Islands, Cuba, Netherlands Antilles, Turks and Caicos Islands).¹²⁷

Within the United States Eurasian collared-doves are found year-round in a majority of states. The birds are absent from the northeast states (e.g. the area stretching approximately from Pennsylvania to Maine), and are only sparsely seen in states including Ohio, Michigan, and Virginia.¹²⁹

D. Distribution in Los Angeles County

Observational data from traveling counts indicates that Eurasian collared-doves are ubiquitous throughout Los Angeles County and common in all seasons.¹²⁸

E. Ecological Impact

Eurasian collared-doves' ecological impact is relatively benign, based on to-date research. While they have bred quickly and spread rapidly through the United States, particularly in areas already subject to human disturbance (e.g. cities, roads, agricultural areas), their documented detrimental effects are limited.^{130 131} The species' primary effect is competition with other bird species for food, especially other dove species (e.g. Mourning dove *Zenaida macroura* and turtledove *Streptopelia turtur*), leading to reductions in biodiversity among competing bird species.¹²⁸ However, research on the magnitude of this effect is mixed, and competitive behavior may have a muted effect on mourning dove populations.¹³²

¹²⁹ "Eurasian Collared-Dove." Eurasian Collared-Dove - Introduction | Birds of North America Online. Accessed June 18, 2019. <https://birdsna.org/Species-Account/bna/species/eucdov/introduction>.

¹³⁰ Camacho-Cervantes, Morelia, and Jorge E. Schondube. "Habitat Use by the Invasive Exotic Eurasian Collared-Dove (*Streptopelia decaocto*) and Native Dove Species in the Chamela-Cuixmala Region of West Mexico." *The Wilson Journal of Ornithology* 130, no. 4 (2018): 902. doi:10.1676/1559-4491.130.4.902.

¹³¹ Fujisaki, Ikuko, Elise V. Pearlstine, Frank J. Mazzotti (2010). "The rapid spread of invasive Eurasian Collared Doves *Streptopelia decaocto* in the continental USA follows human-altered habitats." *International Journal of Avian Science* 152(3): 622-632. Doi: <https://doi.org/10.1111/j.1474-919X.2010.01038.x>

¹³² Poling, Trisha D., and Steven E. Hayslette. "Dietary Overlap and Foraging Competition Between Mourning Doves and Eurasian Collared-Doves." *Journal of Wildlife Management* 70, no. 4 (December 13, 2010): 998-1004. doi:10.2193/0022-541x(2006)70[998:doafcb]2.0.co;2.

The species is a carrier for the Pigeon circovirus, which is deleterious to other bird species in the Columbiformes family, which includes doves and pigeons.¹²⁴ It also acts as a carrier and amplifying species for West Nile Virus.

F. Human Health Impact

As aforementioned, Eurasian collared-doves act as a carrier and amplifier for West Nile Virus, which can increase the prevalence of infected mosquito vectors in an area.¹²⁴ However, the degree to which the species may affect virus levels in a given area is subject to numerous complex factors, especially local conditions.¹³³ Further research is likely required to establish what role the birds play in a given area with respect to disease transmission.

G. Economic Cost

Eurasian collared-doves can be detrimental to agricultural interests, eating and fouling grain products in farm areas.¹²⁴ There may also be economic ramifications to the potential human health hazard of increased West Nile Virus incidence. However, at the time of this report, no quantitative data has been identified which can put a monetary value on these impacts.

H. Best Management Practices

Established management practices for Eurasian collared-doves are limited. Due to their numbers and invasive status, the species has become a popular game bird in some areas and is open to legal hunting in several states.^{124 133} However, given the large population size and high breeding capabilities of the species, this is unlikely to make a significant impact, and eradication is very unlikely. They are naturally preyed on by some species, such as birds of prey, but it is unlikely that biocontrol can be used to attain large-scale population control.

Potential management strategies could focus on land management practices that minimize disturbance of new areas, limiting spread of the Eurasian collared-dove range; and on the prevalence of bird feeders and other food sources that have made suburban and urban areas hospitable to species populations. However, there is no concrete research or data that explores these possibilities identified at the time of this report, and the latter option may prove infeasible.

¹³³ Panella, Nicholas A., Ginger Young, and Nicholas Komar. "Experimental Infection of Eurasian Collared-dove (*Streptopelia Decaecto*) with West Nile Virus." *Journal of Vector Ecology* 38, no. 2 (November 11, 2013): 210-14. doi:10.1111/j.1948-7134.2013.12032.x.