NATIVE CALIFORNIA OAKS AND THE GOLDSPOTTED OAK BORER (*Agrilus coxalis*) IN THE SAN DIEGO RIVER PRESERVES

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Abstract

San Diego County is home to a wide variety of ecosystems with coastal, mountain, and desert areas, each with its own unique assemblage of plants and animals. The southern oak woodlands of California represent crucial habitat for plants and wildlife, improve ecosystem services, and contribute to aesthetics. Unfortunately, extensive mortality of oak species due to the introduction of an invasive insect, the Goldspotted Oak borer (GSOB), has been recorded since 2002 in San Diego County, where more than 80,000 trees across 620,000 acres have been killed and the infestation is increasing as the population of this pest grows. The four primary host species, the Coast live oak, Canyon live oak, California black oak and Engelmann oak, cover over 39 million acres in California and it is possible that other oaks overlapping the ranges of these species may become hosts also. This study focuses on monitoring activities for Goldspotted oak borer infestation in two properties of the San Diego River Park Foundation, the Eagle Peak Ranch/Temescal Creek Gateway and the Boulder Creek Preserve. Results suggest that there is a significant difference in infestation rate between the two study sites, with Eagle Peak Ranch/Temescal Creek Gateway more highly infested by the GSOB than Boulder Creek Preserve. Potential explanations for the difference in infestation include the different elevation and oak density of the two locations and the proximity to a campground that has been heavily impacted by the invasive beetle, but further investigation needs to be conducted. Several techniques to reduce tree mortality and prevent GSOB infestations are provided, such as quarantine regulations to prohibit the movement of potentially infested host material out of the infested area and increase monitoring of GSOB in non infested areas, for both forest landowners and urban dwellers.

Introduction

Biodiversity hotspots represent areas of concentrated biodiversity and high conservation priority. These hotspots comprise only 1.44% of the Earth's land surface, but account for about 60% or more of the remaining diversity of life on Earth, considering all groups of species (Spencer, White, & Stallcup, 2001). Southern California is considered one of 36 global biodiversity hotspots, which support the greatest concentration of living species, especially those occurring nowhere else outside their defined geographic area (Mittermeier, Turner, Larsen, Brooks & Gascon, 2011).

Within Southern California, San Diego County is characterized by different habitats, each with its own unique biodiversity. One of these habitats is the California Oak Woodland, in which several evergreen and deciduous oaks are dominant or co-dominant canopy species, such as the Coast live oak (*Quercus agrifolia*), the Engelmann oak (*Quercus engelmannii*), the Canyon live oak (*Quercus chrysolepsis*) and the California black oak (*Quercus kelloggii*) (See Appendix). The Engelmann Oak can be found in southern to eastern San Diego County, the California black oak is found all over California, and the Coast live oak is found along the southern and central coast of California (Coleman & Seybold, 2008). The Canyon live oak (*Quercus chrysolepsis*) was not included in this research project, since the species is not present in the study areas.

Unfortunately, extensive mortality of these oak species has been recorded since 2002 in San Diego County: more than 80,000 trees across 620,000 acres have been killed and the infestation is increasing (United States Department of Agriculture Forest Service, 2008). According to Coleman and Seybold (2008), for several years a reduction in annual rainfall was hypothesized to be the factor causing oak mortality. However, in 2008 the main cause of oak tree mortality in San Diego County was identified in woodborer damage to the main stem of oaks. This was caused by an exotic woodboring beetle later identified by the Plant Pest Diagnostic Laboratory, California Department of Food and Agriculture as the Goldspotted oak borer (*Agrilus coxalis)* (Coleman & Seybold, 2008). Each year, timber losses in California forests due to bark beetle attack exceed those caused by wildland fire (Sanborn, 1996). The presence of the GSOB in southern California was first recorded in 2004 during an exotic woodborer survey.

The Goldspotted oak borer is native to southeastern Arizona, southern Mexico, and northern Guatemala, where it is not causing any damage, because of the presence of natural predators and native oak species that have co-evolved with the borer. Indeed, colonization of trees by the GSOB and its association with oak mortality has not previously been documented within the beetle's known native distribution (Coleman & Seybold, 2008). However, as an invasive species in San Diego County, the insect is playing a major role in on-going oak mortality on federal, state, private, and Native American lands. According to Coleman et al. (2015), in its native range, rates of GSOB infestation and tree mortality are 4% and 2% respectively, while these rates have been much higher, 90% and 45% respectively in the invaded range in southern California. Invasive species, alien species, or exotic pests, are common names that categorize non-native animals, microbes, diseases, or plants that threaten native species and the overall biodiversity (Pejchar & Mooney, 2009). When talking about invasive species, insects are considered one of the main invaders in terrestrial environments (California Academy of Sciences, 2014). Invasive species become a pest outside of their native range, by reducing and outcompeting native species. This ultimately leads to extinction of local animals or plants resulting in the drastic modification of native ecosystems (Raghubanshi et al. 2005; Hoddle, 2004; Brown & Sax, 2004).

The authors hypothesized that this invasive species was either recently introduced to California through oak firewood imported from other parts of the insect's native habitat, or it has expanded its range. In addition, drought affecting the area may have predisposed trees to mortality from GSOB (Katovich, Munson, Ball, & Mc Cullough, 2000). As a consequence, the GSOB has heavily infested oaks in San Diego County, due to lack of natural predators and low resistance by local oak species (Coleman & Seybold, 2008). The initial infestation may have occurred around Descanso, CA, where the first oak deaths were reported (Camilli, 2009). In 2012, oaks in Riverside and additional areas in San diego and Orange County were infested, mainly due to introduction of infested firewood (Coleman et al. 2015). Because native trees did not co-evolved with the borer, they are not adapted to defend themselves from an attack. Although acorn woodpeckers, *Melanerpes formicivorus*, and Nuttall's woodpecker, *Picoides nuttallii*, are known to forage on goldspotted oak borer larvae, their number is not big enough to keep populations under control. As of today, there are no other natural enemies of the GSOB known in California (Hishinuma, Coleman, Flint, & Seybold, 2011; Coleman et al., 2011).

Oak trees that are more prone to be attacked by the invasive beetle are usually weakened by different factors such as drought, defoliation, disease, or improper tree care (Corella, K.S., Owen, D.R., 2015). GSOB larvae feed under the bark primarily at the interface of the phloem and xylem, the nutrient and water conducting tissues of plants on the main stem and larger branches (Furniss & Carolin, 1977). In addition, they also feed on the cambium, which is responsible for the growth of the tree, resulting in limb and branch dieback (United States Department of Agriculture Forest Service, 2008; Camilli, 2009). Trees die after several years of extensive mining by larvae, which prevents water and nutrients from flowing through the trees. According to Coleman and Seybold (2008), infestations have been observed only in older, mature oaks, while they have never been seen in small diameter oaks with less than 12 cm (5 inches) at breast height.

Adult GSOBs, which complete one generation in a year, are about 10 mm long and 2 mm wide and can be identified by the six golden-yellow spots on the dark green forewings. Mature larvae are about 18 mm long and 3 mm wide, legless, white, and have a long slender appearance. Pupae are found in the outer bark and resemble adults, but are commonly white in color (Coleman & Seybold, 2008; Coleman et al., 2015) (see Appendix B). Adult GSOB feed and mate on the foliage of the oak trees (Camilli, 2009). However, they do not impact tree health, causing only minor damage to oak leaves (Coleman et al., 2015).

The oak trees display external symptoms of GSOB infestation that include premature twig dieback and crown thinning that worsens progressively over several years; presence of D-shaped emergence holes used by adults for emerging through the outer bark after they have completed pupation; black, wet staining or dark red bleeding on and beneath the bark, caused by larval feeding and resulting from a build-up of tree sap around patches of dead phloem; woodpecker damage caused by the removal of bark in search of larvae and pupae (see Appendix C). The feeding galleries, constructed by the larvae of GSOB underneath the bark, are dark in color and usually occur at the base of trees and extended upward to approximately 9 m along the main stem and larger branches (Coleman & Seybold, 2008). When adult development is complete, the adults chew an emergence hole through the bark and exit the tree. Adult exit holes are D-shaped and about 3 mm in width. According to Coleman et al. (2011), the size and shape of D-shaped exit holes are symptoms of GSOB infestation, because other flat headed borers are rare on oaks in southern California.

Widespread oak mortality causes loss of food and habitat for wildlife and can also increase the probability and severity of wildfire. Furthermore, the loss of heritage oak trees, pest control costs, and the disposal of dead trees for preventing wildfires, are all consequences of the GSOB attack (United States Department of Agriculture Forest Service, 2008).

In view of all this, many conservation organizations in San Diego County are working together in order to eradicate the borer or limit the damage it is causing to native oaks. The present study focuses on monitoring activities for Goldspotted oak borer infestation in two properties of the San Diego River Park Foundation, the Eagle Peak Ranch/Temescal Creek Gateway and the Boulder Creek Preserve. The San Diego River has long been a source of life and vitality in the San Diego region, because it is crucial for the local biodiversity. With a watershed of more than 440 square miles, the river flows for 52 miles from the mountains of West Julian to the Pacific Ocean (www.sandiegoriver.org). The Eagle Peak Ranch/Temescal Creek Gateway is 374 acres, with elevation of 1100 m (3,500 feet), characterized by montane meadow, disturbed grassland, riparian oak woodland, and southern maritime chaparral. The Boulder Creek Preserve is 13 acres, with elevation of 810 m (2,661 feet), characterized by riparian oak woodland, riparian scrub, and disturbed grassland.

The goal of this project is to determine if differences do exist between the two areas of study, by asking the question: are there more oak trees infested by the Goldspotted Oak Borer in the Eagle Peak Ranch/Temescal Creek Gateway or in the Boulder Creek Preserve?

The hypothesis is that Eagle Peak Ranch/Temescal Creek Gateway is more infested by the GSOB than Boulder Creek Preserve because of higher oak density in the first study site and its proximity to a campground that has been heavily impacted by the invasive beetle.

Methods

Study sites

Ground surveys at two different sites, properties of the San Diego River Park Foundation, were conducted in order to determine the rate of GSOB infestation for both areas (see Appendix D). Ground surveys are the most effective method for detecting GSOB infestations and determining the level or injury caused by the beetle. However, they are time consuming and GSOB-caused injury symptoms are often not obvious during the early stages of infestation.

In Boulder Creek preserve the ground survey was conducted on September the 15th from 9.30 am until 01.00 pm by the author and one of the San Diego River Park Foundation volunteers under the supervision of an expert in identifying oak species. The two oak species found in the preserve were the Coast live oak (*Q. agrifolia*), which is the predominant species in the area and the Engelmann oak (*Q. engelmannii*).

In the Eagle Peak Ranch/Temescal Creek Gateway the ground survey was conducted on September the 22nd from 09:00 am until 1:00 pm by the author with the help of a San Diego River Park Foundation volunteer. The two oak species found in the preserve were the Coast live oak (*Q. agrifolia*), which is the predominant species in the area and the California black oak (*Q. Kelloggii*).

For both locations, oak trees were selected and monitored for GSOB infestation based on accessibility. In order to compare the data between the two study sites, the same number of trees was inspected. Some oak trees in the study areas were not accessible because of the presence of poison oak, so they were not monitored. In addition, only medium and big size trees were selected for the monitoring activity.

Rating system and data analysis

For the purpose of this study, the monitoring efforts focused on three injury symptoms caused by GSOB: the degree of crown thinning, presence of D-shaped emergence holes, and density of bark staining.

A health rating system developed by Coleman et al. (2015) was used to determine the degree of goldspotted oak borer injury and assist with management decisions. For the purpose of

this study the rating system was simplified as follows: a) crown rating (1-3) whereby 1= full, healthy crown, 2= moderate twig dieback and thinning, 3= tree is dead, no living foliage; b) emergence hole rating (0-2) whereby 0 = no emergence holes, 1 = less than 10 D-shaped emergence holes on the lower main stem but at least one hole detected (<6 feet or 1.8 m), 2 = greater than 10 emergence holes on the lower main stem (<6 feet or 1.8 m); c) bark staining rating (0-2) whereby 0 = no bark staining, 1= one to 5 areas of staining on the lower main stem (<6 feet) and 2= greater than 5 stained areas on the lower main stem (<6 feet).
The rating values are based on available biological information and the subjective judgment of the author.

The rating system described above was used for collecting data during the ground surveys and for statistical analysis. Infestation was rated as having a non-zero score for either emergency hole and/or bark staining, while a score of zero in both categories was used to determine the tree was not infested. If trees showed a score of zero for both emergency hole and bark staining they were considered healthy regardless of the crown rating score.

Using these guidelines, an additional infestation scoring system (1-4), from slightly infested to highly infested tree, was created as presented in Table 1:

Table 1: Infestation scoring system resulting from emergence hole rating and bark staining rating

Infestation score	Description	Emergence hole rating	Bark staining rating
1	Slightly infested	1	0
		0	1
2	Moderately infested	2	0
		0	2
		1	1
3	Infested	2	1
		1	2
4	Highly infested	2	2

Table 1 shows all the possible scenarios coming from the data collection. The numbers recorded under emergence hole rating and/or bark staining rating give the infestation score on the left. For example, if a tree presented emergence hole rate = 1 and bark staining rate = 0, the level of infestation was 1. If a tree presented emergence hole rate = 2 and bark staining rate = 1 the rate of infestation was 3 and so on.

Pearson Chi-square tests were performed using the Minitab version 17 software for comparing the infested trees in Eagle Peak Ranch/Temescal Creek Gateway and Boulder Creek preserve, in order to determine if there was a significant difference in the infestation rate between the two study sites.

Results

Boulder Creek preserve

A total of 50 oak trees, 42 Coast live oak and 8 Engelmann oak, were assessed for GSOB infestation.

A summary of the data collected is shown in Table 2:

Table 2: Summary of data collection for Boulder Creek preserve

Oak species	Nr of trees	Crown rating	Description	Nr of trees	Emergence hole rating	Description	Nr of trees	Bark staining rating	Description	Nr. Of trees
Coast live oak	42	1	healthy crown	30	0	no holes	32	0	no staining areas	38
Engelmann oak	8	2	moderate twig dieba	18	1	less than 10	14	1	less than 5	9
		3	tree is dead	2	2	greater than 10	4	2	greater than 5	3
	50			50			50			50

Of the 50 trees that were monitored, 30 oak trees had a full, healthy crown while only 18 trees had a moderate twig dieback and thinning. Thirtytwo oak trees had no D-shaped holes visible on the lower main stem, while 14 of them had less than 10 holes. 38 oak trees showed no bark staining on the lower main stem.

Eagle Peak Ranch/Temescal Creek Gateway

A total of 50 oak trees, 42 Coast live oak and 8 California black oak, were assessed for GSOB infestation.

A summary of the data collected is shown in Table 3:

Table 3: Summary of data collection for Eagle Peak Ranch/Temescal Creek Gateway

Oak species	Nr of trees	Crown rating	Description	Nr of trees	Emergence hole rating	Description	Nr of trees	Bark staining rating	Description	Nr. Of trees
Coast live oak	42	1	healthy crown	10	0	no holes	13	0	no staining areas	18
California black oak	8	2	moderate twig dieba	35	1	less than 10	10	1	more than 5	12
		3	tree is dead	5	2	greater than 10	27	2	greater than 5	20
	50			50			50			50

Of the 50 trees that were monitored, only 10 oak trees had a full, healthy crown, while 35 trees had a moderate twig dieback and thinning and 5 of them were dead with no living foliage left. Twentyseven oak trees had more than 10 D-shaped emergence holes visible in the lower main stem. Eighteen oak trees showed no bark staining on the lower main stem and 20 had more than 5 visible bark stains.

A summary of the infested and non-infested trees for both areas is shown in Figure 1.

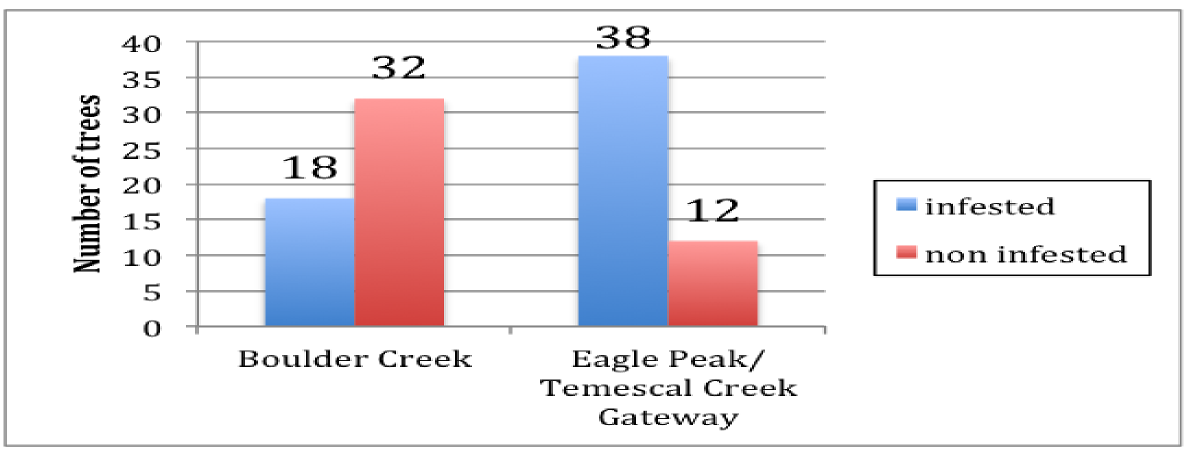

Figure 1: Comparison of infested and non-infested trees for the two study sites.

Infestation was rated as having a non-zero score for either emergency hole rating and/or bark staining rating and data was summarized regardless of the oak species. A score of zero in both infestation categories was used to determine the tree was not infested. Crown rating data was not taken into consideration for this analysis. The data shows a dramatic difference in the infestation rate by tree location. In Boulder Creek preserve 18 trees were recorded as infested, while in Eagle Peak/Temescal Creek Gateway 38 trees were reported as infested.

Using the infestation scoring system (1-4) a further investigation of the infestation differences by tree location was conducted.

The results are reported in table 4.

Table 4: Analysis of rate of infestation by location and infestation summary score

Infestation score	Description	Emergency hole rating	Bark Staining rating	Nr. Of trees in Eagle Peak/Temescal Creek Gateway	Nr. Of trees in Boulder Creek preserve	Total frequency in Eagle Peak/Temescal Creek Gateway	Total frequency in Boulder Creek preserve
1	slightly infested	1	0	3	5	**4**	**5**
		0	1	1	0		
2	moderately infested	2	0	3	1	**9**	**8**
		0	2	0	0		
		1	1	6	7		
3	infested	2	1	5	2	**6**	**4**
		1	2	1	2		
4	highly infested	2	2	19	1	**19**	**1**
				38	**18**	**38**	**18**

Multiple Pearson Chi-square tests were performed to look at the relationship between infestation score, as measured by Emergency Hole score and Bark Staining score, and tree location (Boulder Creek preserve vs. Eagle Peak/Temescal Creek Gateway). For details about the Chi-square tests results see Appendix E. A summary of the Chi-square results is shown in Table 5:

Table 5: Summary of Chi-square test results. Statistical significance $p<0.05$

Chi-square test	p-value	Degrees of freedom
Total frequency	0.012	3
Infestation rate 1	0.2357	1
Infestation rate 2	0.312	1
Infestation rate 3	0.260	1

The Pearson Chi-square Test of the total frequency of infestation between the two study sites shows a significant difference between infestation rate and tree location with a p-value = 0.012. Statistical significance was assigned at $p < 0.05$. Degrees of freedom = 3.
Differences between the two study sites for the 4 infestation rates were also investigated using a Pearson Chi-square Test.
Infestation rate 4 was the result of only one combination (2-2), therefore no Chi-square test was performed for this rate.

Since there were no statistical differences in infestation rate 1, 2 and 3, analysis of total infestation score and tree location as shown in table 4 is not affected by how the total frequency was calculated.

Discussion and conclusion

GSOB is known to injure and kill four native species of oak: Coast Live Oak, California Black Oak, Canyon Live Oak and Engelmann Oak. Results show that for both study sites, coast live oak was the predominant species. In addition, as stated by Hishinuma, Coleman, Flint, & Seybold (2011), GSOB can injure Engelmann oak, but attacks have not caused significant tree mortality on this species.

The results of the ground surveys done at the two locations, the Boulder Creek preserve and the Eagle Peak/Temescal Creek Gateway, show a higher infestation in the second study site. In this assessment, two morphological attributes, exit holes and bark staining, were definitive for identifying GSOB injury. Statistical analysis shows a significant difference in the infestation rate between the two locations. This significance is driven by the emergence hole score and bark staining score of 2 at a much higher frequency in Eagle Peak/Temescal Creek Gateway as compared to Boulder Creek Preserve (See Appendix E). This is also confirmed by looking at the crown rating in the two locations, where 30 out of 50 trees had a full healthy crown in Boulder Creek preserve, while only 10 out of 50 trees had a full, healthy crown in Eagle Peak/Temescal Creek Gateway (see Table 2 and 3). Tree crowns appeared to thin and die back progressively as the health of trees declined. Trees with visible insect damage showed signs of premature leaf drop, twig dieback, and branch die off. In addition, trees with extensive crown thinning appeared gray when compared to the dark green color of healthier crowns. Initial signs of crown thinning begin at twig ends and progress down to larger branches. Since crown thinness can be the consequence of different types of stressors, canopy condition may be a poor indicator for determining GSOB injury levels. Results show that many trees scored at 2 for crown rating, had no emergence holes or bark staining, indicating that the thinning of the crown was not caused by GSOB infestation.

There are three potential explanations for the significant difference in infestation rate between the two study sites. First, it is possible that GSOB attack might depend on elevation of the two locations. Eagle Peak/Temescal Creek Gateway is 1100 m (3500 feet) in elevation, while Boulder Creek preserve is 810 m (2661 feet). However, no correlation between elevation and rate of infestation has been observed by any other studies so far. Second, another explanation might be the proximity of Eagle Peak/Temescal Creek Gateway to William Heise County Park, which is a campground that has been heavily impacted by GSOB because of firewood. As of May 2015, 2,800 oak trees have been removed from the park. It is known that one of the causes of new infestations is through beetles emerging from transported firewood. Third, oak density is higher in Eagle Peak/Temescal Creek Gateway than in Boulder Creek, so the first location was more prone to be attacked by the invasive beetle. The closer the oak trees are, the higher the probability for the adult GSOB to mate and lay eggs in different trees.

Additional surveys are needed to determine the complete distribution of the GSOB at the two sites and further research is crucial to determine the developmental and activity periods, level of within-tree host utilization, range of suitable hosts, and suppression options. Coleman et al. (2011) stated that oak mortality is commonly associated with different factors, which can be long-term stresses, such as air pollution and topography, or inciting factors that are associated with drought, frost injury, or insect defoliation, or infections by root disease and fungi, or colonization by wood boring insects. According to the results of their study, drought stress is not acting as an inciting factor for oak mortality (Coleman et al., 2011). On the contrary, another study shows that trees are drought stressed in San Diego, which decreases their ability to fend off insects, including the invasive goldspotted oak borer (www.GSOB.org). Further investigations about the high tree mortality levels attributed to the GSOB infestation need to be developed.

Oaks killed by the GSOB have only been found in San Diego County so far, mainly in city public lands, Native Americans lands, public parks, camping sites, along roads, ranches, rural and urban residences. However, the risk is that the borer attacks will spread further north beyond the county line. This might happen through adults flying from infested trees to healthy ones and through infested firewood.

Since GSOB has caused significant economic, ecological, cultural, and aesthetic losses to the region, different management options are proposed. Quarantine regulations are needed for regulating the movement and use of firewood and other wood materials, in order to avoid the risk of spreading the GSOB infestation. In a survey conducted by the Nature Conservancy, one in twenty Americans said they moved firewood long distances, more than 50 miles (California Oak Mortality Task Force, 2010). Regulatory measures should be enforced in order to prohibit transportation of potentially infested wood. In addition, for already infested host material treatments should be applied, such as debarking and chipping. Following tree removal, grinding wood to less than 2.5 cm particle size can get rid of wood borers from infested wood. Therefore, hazard tree removal might be the solution, even if disposal measures for infested wood require a lot of money. Moreover, buying locally cut firewood can prevent invasive pests and diseases from attacking non infested areas. Furthermore, increase monitoring of GSOB in non infested areas of the state that have host habitat and are likely receptors of beetles being transported in firewood should be promoted. Traps and ground surveys are effective at detecting GSOB in areas with or without observed tree mortality. Applying insecticides on high value oak trees in areas potentially exposed to the GSOB is the only preventive management option currently in place (Smith, 2009). However, information on using insecticides to manage GSOB is limited. Insecticide treatments for controlling wood borers are more effective for preventing infestation of healthy trees and not for controlling larvae in infested trees (Hishinuma, Coleman, Flint, & Seybold, 2011). In addition to regulation, outreach is likely the most effective tool to prevent the dispersal of GSOB. Education is ongoing to inform the public about the potential to move GSOB into currently not infested areas via firewood for example. Furthermore, communication and collaboration with different stakeholders should be promoted: urban foresters, homeowners, managers and arborists should be informed to increase awareness of GSOB and encourage to take actions toward preventing further spread and providing training on how to detect the symptoms of the beetle attacks. According to a Nature Conservancy poll, when people learn why they shouldn't transport firewood long distances, the vast majority is willing to buy it where they burn it (California Oak Mortality Task Force, 2010).

Funding, partnerships, networking, research, educational outreach, and strategic regulation are key components of oak protection. Currently, management programs for GSOB are focused on limiting its spread into new areas and protecting healthy trees. Additional research needs to be done on insecticides or other tools to control GSOB in infested trees. A lot has been done locally so far. San Diego County government agencies in collaboration with the University of California have established a Committee for learning more about this invasive pest and how to control and eradicate it. Education through outreach publications to enforce firewood regulations and workshops for professionals and citizen scientists to involve them in the GSOB monitoring system are crucial for reducing GSOB's spread and severity of damage.

Action and reflection on citizen science component

The webpage related to this project was designed for educating people about the Goldspotted oak borer, the threat that this invasive species poses to oak habitats in San Diego County, and what management actions are needed in order to stop the infestation from spreading and attacking new oak trees. To achieve this goal it is important that people know how to identify the GSOB and symptoms and signs of infestation and what to do to make a difference and keep native California oaks healthy.

The website is entitled "Native California Oaks need your help" and can be reached through the following link: http://beaheroforoakspecies.weebly.com.

The website was designed starting from an overview about the GSOB with information about what an invasive species is, how the GSOB and larvae look like, and what the primary host species are. A page is dedicated to the present project with preliminary results from the initial analysis and personal photos taken during the ground surveys conducted to collect the data. Under the "what you can do" section suggestions on best management practices for preventing the spread of GSOB are given, such as managing oak firewood properly, treating cut wood, biological control and chemical control. In order to facilitate participation in the citizen science portion, a page describing in detail symptoms of infestation with visual aids was added. The website also contains a section where local citizens can contribute their observations to the project, by identifying GSOB infested trees in their areas. They are asked to provide the location of the trees in order to highlight areas in San Diego County attacked by the borer.

The intended audience is the local community and the goal is not only to collect information about infested trees but also to help people take actions in order to prevent the invasive beetle from establishing and killing new oak trees. Throughout the website, information on resources and organizations people can refer to is also provided, so that local citizens can get involved beyond this project too.

During my AIP Master program this project belongs to, I had the chance to learn how citizen science, by combining investigation, education, and action, can lead not only to the generation of new knowledge but also to action for social change. This is the right tool to encourage the public to become knowledgeable, empowered and active citizens through full and authentic people participation and collaboration.

One of my Master Plan goals is to encourage people towards both local and global conservation actions, by cultivating in people an ethic of earth stewardship, developing people's sense of empowerment, providing people with learning opportunities, and helping people learn how to make tangible, physical changes in the environment. The present project will add a step toward this goal and give me the opportunity to collaborate with organizations that will help me grow as a person and as a scientist.

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The Goldspotted Oak Borer (Agrilus coxalis). Photo retrieved from: http://ucanr.edu/sites/gsobinfo/

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Appendix A


Left: Coast Live Oak (*Quercus Agrifolia*). Photo retrieved from: http://calscape.org/view.php?pl=3133&img=5413

Right: Coast Live Oak leaves. Photo retrieved from "Goldspotted Oak Borer: field identification guide".


Left: Engelmann Oak (Quercus Engelmannii). Photo retrieved from: https://en.wikipedia.org/wiki/Quercus_engelmannii
Right: Engelmann Oak leaves. Photo retrieved from "Goldspotted Oak Borer: field identification guide".


Left: California Black Oak (Quercus kelloggii). Photo retrieved from: http://www.stevenkharper.com/californiablackoak.html
Right: California Black Oak leaves. Photo retrieved from: “Goldspotted Oak Borer: field identification guide”.

Coast live oak: is an evergreen tree, 10 to 25 m tall, with a broad, dense crown and widely spreading branches. It grows in well-drained soils on bluffs, gentle slopes, and canyons, and can be found up to 1400 m (4,600 feet) in elevation (Bleier, 1993).
Engelmann oak: is a medium sized evergreen tree reaching up to 10 m, generally a single, short crooked trunk with large twisted, spreading limbs forming a sparse crown. It grows in savannas and woodlands above the dry coastal plain, and can be found up to 1300 m (4,300 feet) in elevation where colder winters prevail (Hagen, 1990).
California black oak: is a deciduous, hardwood tree with a broad rounded crown and 10-25 m tall. It is the largest mountain oak in the West and surpasses all other California oaks in volume, distribution, and altitudinal range. It can be found in northern oak woodlands, mixed conifer forests and mixed evergreen forests up to 2400 m (7,900 feet) in elevation (Anderson, 1993).

Appendix B

The Goldspotted Oak Borer (Agrilus coxalis). Photo retrieved from: http://ucanr.edu/sites/gsobinfo/

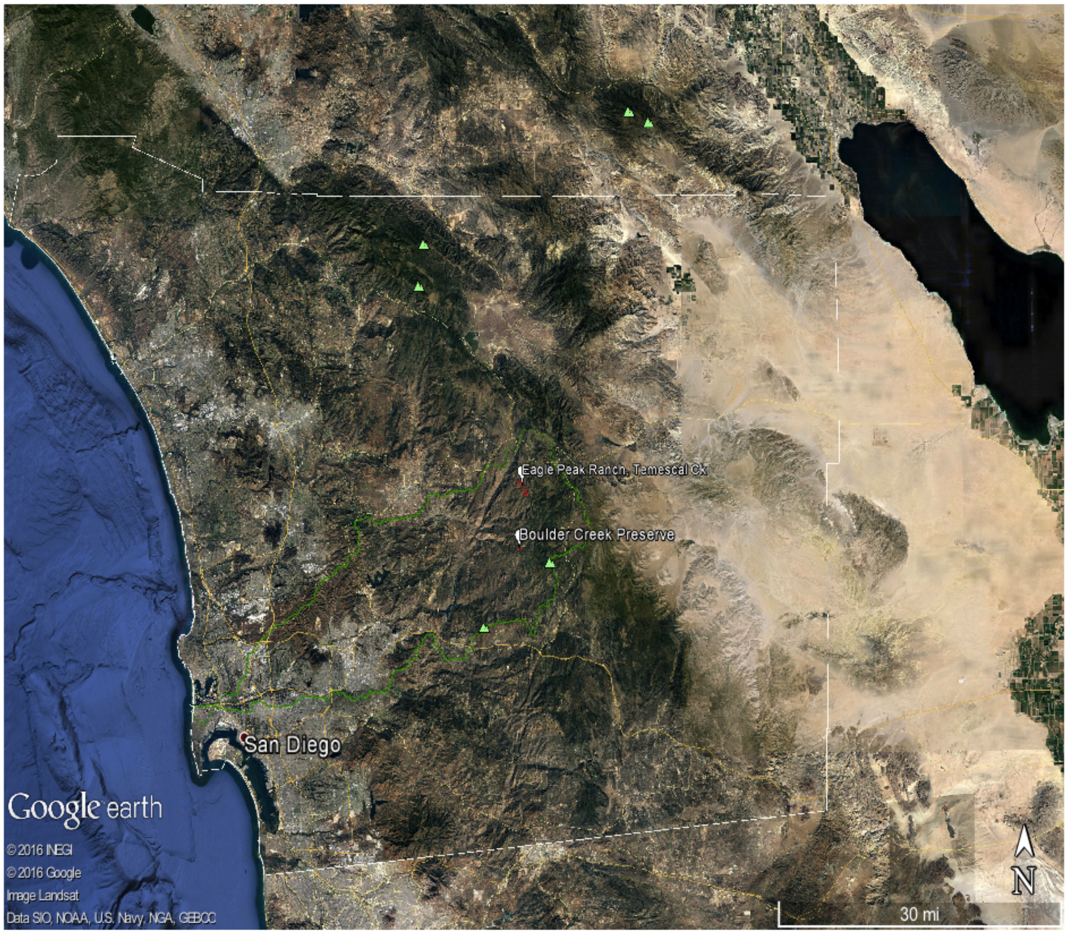
The goldspotted oak borer larvae. Retrieved from : http://ucanr.edu/blogs/gsob/

Appendix C

Left: Bark staining. Right: D-shaped exit holes of GSOB adults.. Photos from: United States Department of Agriculture Forest Service

Left: Larval galleries on the sapwood surface. Centre: Black patches of cambium killed by GSOB after removing the bark. Right: Dying coast live oak following attacks by GSOB. Photos from: United States Department of Agriculture Forest Service

Appendix D



Two study sites retrieved from www.google.com

Appendix E
Statistical analysis performed using Minitab v. 17

1) Pearson Chi-square test conducted on the total frequency of infestation for the two study sites:

```
EP      BC   All

1            4      5    9
       6.107   2.893
       0.7270  1.5348

2            9      8   17
       11.536   5.464
       0.5574  1.1767

3            6      4   10
```

```
       6.786   3.214
       0.0910  0.1921

4            19     1   20
       13.571   6.429
       2.1714  4.5841

All          38      18   56
```

Pearson Chi-Square = 11.035, DF = 3, P-Value = 0.012

2) Pearson Chi-square test conducted on the infestation rate 1 for the two study sites:

Infestation 1:
Emergency Score =1 at EP/BC Bark Staining Score = 0 at BC/EP; 1+0 = 1
Emergency Score =0 at EP/BC Bark Staining Score = 1 at BC/EP; 0+1 = 1

Testing Infestation 1 category differences:

```
EP-1   BC-1  All

1            3      5    8
        3.5556   4.4444
       0.08681  0.06944

2            1      0    1
       0.4444   0.5556
       0.69444  0.55556

All          4      5    9
```

Pearson Chi-Square = 1.406, DF = 1, p=0.2357

3) Pearson Chi-square test conducted on the infestation rate 2 for the two study sites:

Infestation 2:
Emergency Score =2 at EP/BC Bark Staining Score = 0 at BC/EP; 2+0 = 2
Emergency Score =0 at EP/BC Bark Staining Score = 2 at BC/EP; 0+2 = 2 (there were no counts in this category, so it was removed from the analysis)
Emergency Score =1 at EP/BC Bark Staining Score = 1 at BC/EP; 1+1 = 2

Testing Infestation 2 category differences:

```
       EP-2    BC-2  All

1            3      1    4
       2.118   1.882
       0.3676  0.4136

2            6      7   13
        6.882   6.118
       0.1131  0.1273
```

```
All          9       8   17
```

Pearson Chi-Square = 1.022, DF = 1, P-Value = 0.312

4) Pearson Chi-square test conducted on the infestation rate 3 for the two study sites:

Infestation 3:
Emergency Score =2 at EP/BC Bark Staining Score = 1 at BC/EP; 2+1 = 3
Emergency Score =1 at EP/BC Bark Staining Score = 2 at BC/EP; 1+2 = 3

Testing Infestation 3 category differences:

```
EP-3   BP-3  All

1            5      2    7
       4.200   2.800
       0.1524  0.2286

2           1       2     3
       1.800   1.200
       0.3556  0.5333

All          6       4   10
```

Pearson Chi-Square = 1.270, DF = 1, P-Value = 0.260