

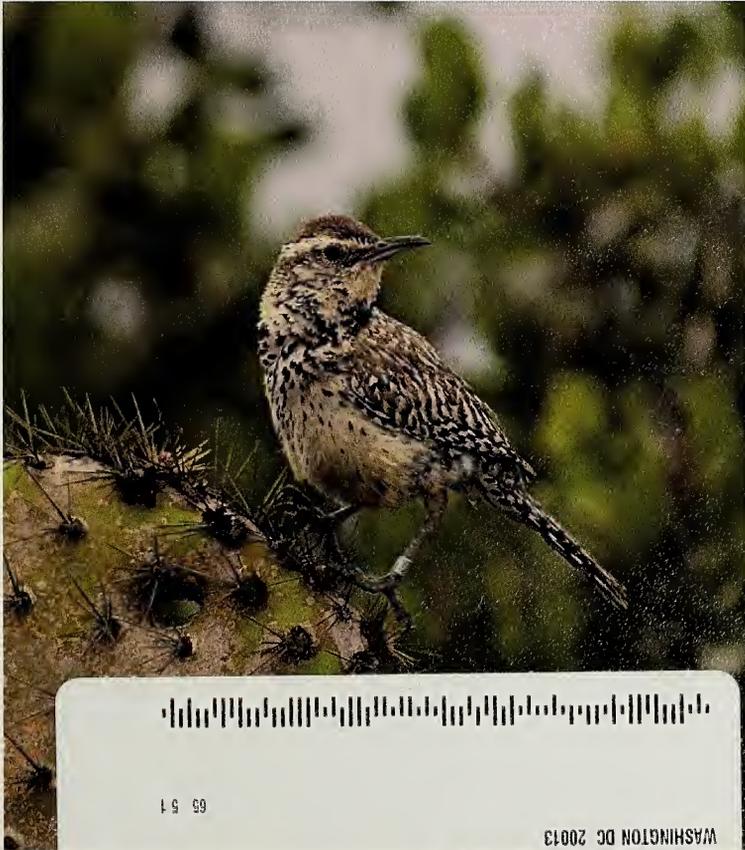
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SOUTHERN CALIFORNIA ACADEMY OF SCIENCES

BULLETIN

Volume 115

Number 3



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Date of this issue 13 March 2017

Site Fidelity of a Coastal Cactus Wren (*Camphylorhynchus brunneicapillus*) on the Palos Verdes Peninsula

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The coastal cactus wren (*Camphylorhynchus brunneicapillus*) is a charismatic, though sedentary bird that inhabits thickets of prickly pear (*Opuntia littoralis* and *O. oricola*) and coastal cholla (*Cylindropuntia prolifera*) in the coastal sage scrub and chaparral habitats of southern California and Baja California, Mexico¹ (Rea and Weaver 1990). Urbanization that took place during the past century, with its attendant habitat loss, has deleteriously impacted this species. On the Palos Verdes Peninsula, coastal cactus wrens occupy cactus habitat contained within the five-hectare Palos Verdes Nature Preserve (Preserve) and undeveloped tracts interspersed between the Preserve and urban development. As such, it is an isolated population that faces threats through loss of genetic diversity.

Recently, two independent investigations have converged to demonstrate a remarkable instance of site fidelity by a single individual. During 2012 and 2013, biologists from the U. S. Geological Survey sampled 620 coastal cactus wrens in Ventura, Los Angeles, San Bernardino, Riverside, Orange, and San Diego Counties to assess the impacts of habitat fragmentation using contemporary genetic analysis (Barr et al. 2015). Birds that were captured for the genetic analysis were banded to prevent re-sampling individuals¹. A total of eight individuals were captured and banded in the Preserve during the second year of this study. Each individual's location and band number was recorded at capture and blood was drawn for the genetic analysis.

In 2014, the Palos Verdes Peninsula Land Conservancy (Conservancy) initiated a Citizen Science Cactus Wren program to utilize volunteers to observe the coastal cactus wrens within the Preserve. The Conservancy manages and restores habitat within the Preserve for several special status species, as well as the coastal cactus wren. The program was designed to return information about how the wrens utilized their habitat, within both existing habitat and newly established areas of habitat. This is important information for the Conservancy in its mission to restore cactus stands within the Preserve's coastal sage scrub habitat.

The volunteers conducted weekly surveys within the Preserve's Alta Vicente Reserve from March through July during the breeding seasons in 2014 and 2015. The surveys were conducted for 20 minute periods at specifically delineated territorial polygons within areas referred to as West and East (Fig. 1). Observations were recorded by the minute and included number of cactus wrens (adult, juvenile, or unknown), presence of predators, and several qualitative behavior patterns from which frequencies could be computed (Table 1). For these surveys, the enthusiastic volunteers took to the field outfitted with binoculars, spotting scopes, and cameras equipped with telephoto lenses.

That coastal cactus wrens spend most of their time moving within the cactus thickets, rising above the cactus for only brief moments, is reflected by the data collected by the Citizen Science

¹ Barr, K. R., A. G. Vandergast, and B. E. Kus. 2013. Genetic structure in the cactus wren in coastal southern California. U.S. Geological Survey, Reston, VA. 27 pp. Available from: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=65007> via the Internet. Accessed 20 February, 2016.



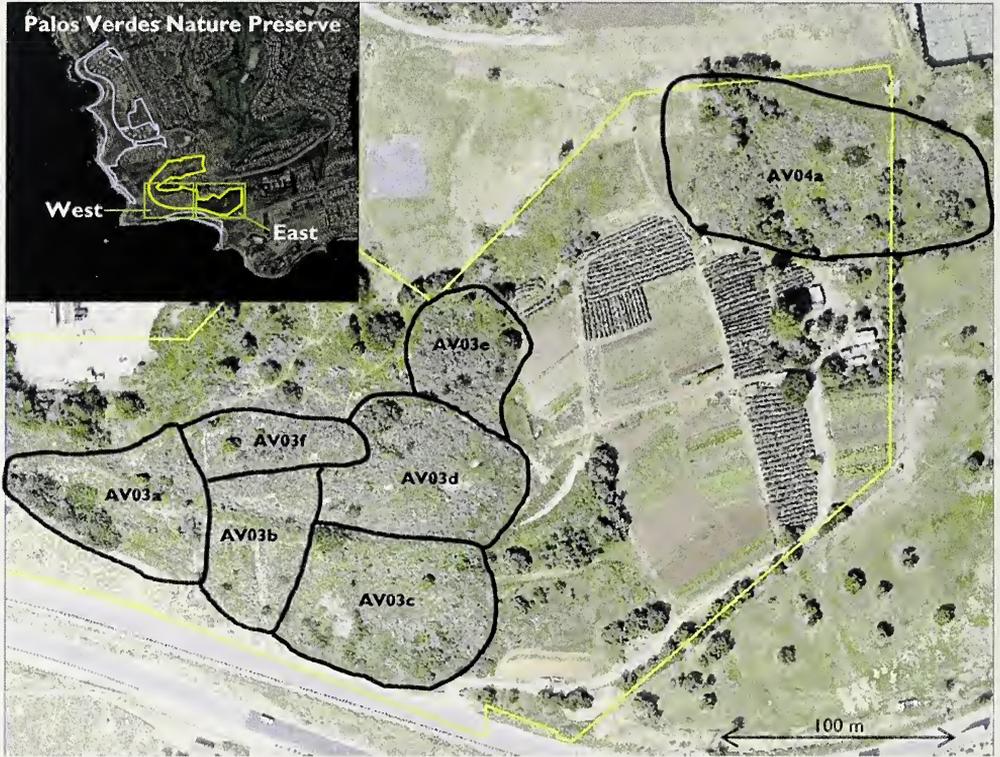


Fig. 1. Alta Vicente West and East are shown in yellow in the upper left-hand box. The territorial polygons are shown in the large map. The farmed cactus is visible as even rows adjacent to polygon AV04a.

Table 1. All observations from the 2015 Citizen Science Cactus Wren Program from 230 twenty-minute surveys at 21 territories at Alta Vicente Reserve from 21 Feb 2015 through 25 Jul 2015. Each territory was observed for 20 minutes and observations recorded by the minute. Occasionally multiple observations occurred within a 1-minute observation interval.

Type of observation	2015	
	Count	Percent
No observation	4101	88.98
Audio observation	65	1.41
Visual observation	213	4.62
Predator observed	32	0.69
Flight out to a different territory	77	1.67
Flight in from a different territory	73	1.58
Defensive/aggressive activity	2	0.04
Copulation	0	0.00
Nesting material in beak	15	0.33
Flight into nest	16	0.35
Flight out of nest	13	0.28
Feeding young in nest	1	0.02
Feeding young out of nest	1	0.02
Total observation intervals	4600	—



Fig. 2. Adult male photographed on 6 Jun 2015 that was banded two years earlier on 12 Jun 2013 as an unknown sex. Image courtesy of Mai Lee.

volunteers in 2015. Aural and visual cactus wren observations occurred at a combined frequency of 6.0% (Table 1). Birds were observed flying into or out of their territories during 2.3% of the observations, whereas activities related to rearing their brood were observed during 1.0% of the observations.

Variations in the throat and breast patterns were used by Citizen Science volunteers to track individuals. In 2014, after witnessing a pair copulate in the West, their distinctive color patterns enabled the volunteers to determine the birds' respective sex. Subsequently, the volunteers tracked the behavior of the pair through their courtship, nesting, and the successful rearing of two chicks. Throughout the nesting season, vocalization and defensive behaviors were primarily the domain of the male while the female tended to the nest and chicks. After fledging, one chick was witnessed mimicking its father's boisterous defensive calls, leading to the conclusion that the young individual was also male.

During the 2015 survey, one of the volunteers captured photos of a wren in the East at polygon AV03c. When processing the photos later that day at home, she noticed that the bird was banded with a single, silver band on its left, lower leg (Fig. 2). Similarly, I photographed the same individual four weeks later on July 4, 2015 in polygon AV03f, and only noticed the band in the photographs, for it was not visible with the naked eye or with binoculars. Each band has a unique number, but unfortunately, the number on the band could not be discerned in any of the photographs.

Earlier in 2013, two cactus wrens captured in polygon AV03c were banded with silver bands on their lower left leg, one a female and the other unknown (Table 2). Due to the obscured band

Table 2. List of cactus wrens captured that were banded at the Alta Vicente Reserve following blood drawn for genetic analysis during the 2012-2013 USGS field effort (from B. Kus (USGS personal communication). All coordinates are in WGS84.

Site	Date banded	Age/Sex	Latitude	Longitude	Band ID*
AV1c	30-Jul-12	Hatch year/Unk	33.74402	-118.40582	DGDG/YEYE : WHWH/Mre
AV2c	30-Jul-12	Hatch year/Unk	33.74411	-118.40117	DGDG/YEYE : YEYE/Mre
AV03c	12-Jun-13	Adult/Unk	33.74257	-118.40328	-/Msi : -/
AV04a	12-Jun-13	Adult/Female	33.74401	-118.40144	-/Msi : -/
AV04a	12-Jun-13	Adult/Male	33.74401	-118.40144	-/ : -/Msi

* Top Left Leg/Bottom Left Leg : Top Right Leg/Bottom Right Leg.

Metal bands: Mre = federal red anodized aluminum band, Msi = federal silver aluminum band. Darvic bands: DGDG = dark green, WHWH = white, YEYE = yellow.

number in the individual photographed during the Citizen Science surveys, we could not directly determine which bird from the 2013 banding effort was being observed. However, the banded individual's behavior indicated that it was a male. The bird was very noisy, acting defensively in the presence of Citizen Science observers. It moved away from its youngsters that were foraging nearby, circling around to perch on a tree tobacco (*Nicotiana glauca*), and vocalize defensively. This was behavior very similar to that displayed by the male observed in 2014 by the Citizen Science observers. Based upon the similar behavior, it was concluded that this bird in the East, originally marked as an unknown at the time of banding, was certainly a male. Scarlett Howell (USGS, personal communication) concurred that this behavior is characteristic of males and that the banded bird was likely the individual identified by them as unknown in Table 2.

The banded bird observed during the 2015 survey was seen at locations throughout the east, including the same polygon where it was banded and later photographed (AV03c). In May, this male was observed foraging for its nestlings, flying out of polygon AV04a into farmed cactus and back to the nest. Later in June, both adults were observed leading their chicks out of their natal area (AV04a) and into a farmed patch of cactus (*Opuntia ficus-indica*). Through June and July, the family was frequently observed in the vicinity of the very polygon in which the male was captured for banding.

Two years after banding, this male was operating in the very same area that it was originally captured, exhibiting a remarkable degree of fidelity to the site. Although cactus wrens are known to be a sedentary species, rarely flying more than one km in distance (Rea and Weaver 1990), this observation provides supporting evidence that this species is indeed, a sedentary bird.

Acknowledgements

This observation was the result of the effort of many. I thank the Palos Verdes Peninsula Land Conservancy's encouragement of research within the preserves that it manages and foresight for creating the Citizen Science program. Much admiration is extended to the USGS biologists who spent two years capturing the birds for sampling and banding while getting closer to cactus than anyone would prefer. Additionally, they provided critical support in preparing this manuscript. Finally, much appreciation is extended to the Citizen Science volunteers who brought their dedication and passions to the field:

2014 Team: Helen Ashford, Bonnie Cohn, Bill Cullen, Joyce Daniels, Rina Gardner, Donna McLaughlin, Evi Meyer, Linda Wedemeyer, and Lowell Wedemeyer.

2015 Team: Phil Carnehl, Bonnie Cohn, Vanessa Cruz, Joyce Daniels, Joan Krause, Donna McLaughlin, Harry McWatters, Mai Lee, Evi Meyer, Nancy Fitzhugh, Marty Lewis, Alex Retana, Lauren Singleton, and Pete Verenkof.

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Rodent Removal of Fallen Joshua Tree (*Yucca brevifolia*) Fruits

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Abstract.—Joshua trees (*Yucca brevifolia*) produce large, indehiscent fruits that contain numerous large seeds. Seed dispersal in this species depends on rodents to dismantle fruits and extract the seeds which they disperse tens of meters from the source. Using camera trapping and fruits tied to bobbins, I show that white-tailed antelope squirrels (*Ammospermophilus leucurus*) and kangaroo rats (*Dipodomys* spp.) moved intact, fallen fruits 6 to 7 m from trees before opening them. Pocket mice (*Chaetodipus fallax* and *Perognathus longimembris*) and pinyon mice (*Peromyscus trueii*) dismantled fruits and harvested loose seeds but did not appear to move them although they readily harvested loose seeds. Mobilizing fruits may be an important, overlooked step in the seed dispersal process, especially if the fruits are indehiscent. Fruit-carrying behavior of rodents described in this study adds to the dispersal distance of Joshua tree seeds.

Joshua tree is an iconic, widespread arborescent succulent of the Mojave Desert. In the late Pleistocene Joshua trees were distributed over southeastern California, southern Nevada, southeastern Arizona, and into much of northern Mexico (Cole et al. 2011). As temperatures warmed during the Holocene, its distribution receded from Mexico, southeastern Arizona and southern California into a considerably smaller patchwork of disjunct areas (Cole et al. 2011; Barrows and Murphy-Mariscal 2012). As climate continues to warm into the 21st Century, modeling suggests that Joshua tree likely will disappear in the southern part of its distribution and perhaps expand north into Nevada (Cole et al. 2011).

The ability of Joshua tree to expand its range in response to the anticipated rapid warming may be limited by seed dispersal that would effectively move it to suitable, unoccupied habitats (Lenz 2001; Cole et al. 2011). Lenz (2001) hypothesized that beginning in the middle Miocene (15.1–11.2 mya) mammals such as gomphotheres, mastadons and mammoths likely were long distance dispersers of Joshua tree seeds. Indeed, he suggested its large, multi-seeded fruit may have evolved in response to consumption by these large mammals. However, following the extinction of megaherbivores in the late Pleistocene, Joshua tree seed dispersal now depends entirely on the more limited dispersal (< 100 m) of rodents in the Sciuridae, Heteromyidae and Cricetidae (Vander Wall et al. 2006; Waitman et al. 2012). Whether extinct megaherbivores dispersed Joshua tree seeds is open to question (Waitman et al. 2012) but it is clear that the role of rodent seed dispersal in relationship to present-day climate warming deserves careful examination.

Joshua trees produce seeds in large, non-fleshy, indehiscent fruits. Seed release and dispersal depends exclusively on rodents breaking into fruits and extracting seeds (Vander Wall et al. 2006; Waitman et al. 2012), although Vander Wall et al. (2006) also noted that rodents dragged some fruits away from the source plant before opening them. Preliminary camera trapping of fallen fruits in 2013 revealed that both white-tailed antelope squirrels and kangaroo rats moved unopened fruits from beneath trees, but it was unclear how many fruits were taken, or how far they moved them. If rodents carry fruits from the source, it would increase the total distance

rodents disperse Joshua tree seeds. The goals of this study were: (1) to determine which rodent species moved fruits from beneath trees and (2) to quantify the distances fruits were carried by rodents in two contrasting Joshua tree habitats.

Materials and Methods

Study Area

The study was conducted in two 7.61-ha areas located approximately 6 km north northeast of Big Bear City, California. Both areas occupy gently sloping (average $< 5^\circ$) topography in the high desert of the San Bernardino Mountains at an elevation of 1800 m. The Cactus Flats (CF) site ($34^\circ 19'73''\text{N}$, $116^\circ 48'85''\text{W}$) has no documented occurrence of fire since 1910 when records first began (fire history maps, Supervisor's Office, San Bernardino National Forest), although a wildfire burned to the southwest edge of the study area in 1946. The Lone Valley site (LV) ($34^\circ 17'84''\text{N}$, $116^\circ 47'49''\text{W}$) is located 3.5 km SSE of CF. There are no documented fires for this area since record keeping began (1910).

The study area has a cold desert climate which is characterized by cold, snowy winters and warm, dry summers. Average annual precipitation (1985 - 2014) based on a spatial interpolation of regional climate stations (PRISM Climate Group, Oregon State University, Website <http://prism.oregonstate.edu> created 6 July 2015) is 313 ± 145 mm SD, most of which falls as snow from November to April. The study area also experiences occasional ephemeral summer and fall rainfall events. Both years of the study occurred during a prolonged drought with 136 mm of precipitation recorded in 2013 (43% of the average) and 255 mm (81% of the average) in 2014.

Vegetation Sampling

At 26 points randomly located at each site, I recorded the vegetation cover and composition using 10-m line transects. From each point I oriented a 10-m tape in a random direction. Every 0.5 m on the transect tape I recorded the following variables that intercepted a point: rock, bare ground, herbs and forbs, litter, coarse woody debris, live or dead shrubs, and live or dead trees. The number of intercepts of each variable on the transect was divided by 20 to calculate percent cover for each transect.

Camera Trapping

I camera-trapped the study areas to identify the species that removed fallen Joshua tree fruits. In each study area, I located 10 camera-trapping stations in a 2×5 grid with spacing of ≥ 90 m between stations. At CF, fruits and seeds were photographed beginning 19 September 2013 and in 2014 beginning 15 July. At LV fruits and seeds were photographed beginning 26 October 2013 and beginning 21 August 2014.

At each station, I attached a BirdCam 2.0 camera (EBSCO Industries, Calera, Alabama USA) to the bole of a Joshua tree ~ 35 cm above the ground. Approximately 75 cm from the lens I placed 5 Joshua tree fruits on the ground and programmed cameras to take a photograph every 1.05 minutes beginning at sunset (~ 1845 hours) for an average of 681 photos in the 12-hrs of dark. Cameras flashed automatically every 1.05 minutes during the night. At sunrise (~ 0630), I replaced missing or partially opened fruits with new ones so that cameras photographed 5 fruits at 1.05-min intervals for 12 hours during the day. For each 12-hour period I recorded the proportion of fruits removed from the camera field or opened within the camera's field of view. I camera-trapped each station for 3 days (72 hours), but I only analyzed the first 12-hr day or

night period when animals removed fruits or seeds from the station. If animals failed to remove fruits or seeds from stations in the 72-hour period, the station was recorded as “not visited”.

I carried out the same 72-hour protocol using Joshua tree seeds that I extracted from fruits collected at CF in 2013. In two side-by-side circular plastic dishes (1.5 cm × 9.0 cm), I placed ~39.2 grams of seeds (to simulate the average number of seeds in 5 fruits) uninfested by yucca moth larvae (*Tegeticula synthetica*) (Borchert and DeFalco 2016). Seeds were neither counted nor weighed after deployment.

Once seeds or fruits were discovered, rodents usually removed them in a rapid series of visits. Trapping showed the average interval between visits (\pm SD) was 7 ± 5.4 minutes ($n = 19$). A species was designated the harvester if there was at least one photograph of the animal in the series of visits, and the time between visits did not exceed 15 minutes. In other words, if there was no photograph of the animal, or if the interval between consecutive visits exceeded 15 minutes, the sequence of visits was not analyzed. The little pocket mouse (*Perognathus longimembris*) could not be distinguished from the San Diego pocket mouse (*Chaetodipus fallax*) in the photographs so they were combined and are referred to as “pocket mice”. Similarly, Merriam’s kangaroo rat (*Dipodomys merriami*) and the Pacific kangaroo rat (*D. agilis*) were combined and are referred to as “kangaroo rats”. Live trapping, however, showed that Merriam’s kangaroo rat was by far the most abundant kangaroo rat species (Borchert and DeFalco 2016).

Fruit Spool-and-Line Method

In the proximal end of fruits 6.0-8.0 cm in length, I drilled a 0.8-mm diameter hole to a depth of 5 cm. In this opening I inserted a 0.8 g bobbin (Danfield, Lancashire UK). At each study site, I established a grid of 52 points (4 × 13) with 35-m spacing between points. I placed a fruit under a Joshua tree (> 1.5 m in height) nearest each point and tied the bobbin thread to a slender bamboo stake pushed into the soil. Some fruits were moved but not eaten. These I revisited daily until they were eaten, or moved and then eaten. Only fruits moved > 1.0 m were considered mobilized outside the Joshua tree canopy. After a fruit was moved, I measured the distance and compass direction to the point where it was taken.

Between 29 July and 31 July 2014 at CF I censused the 52 spool-and-line fruits just before 0630 and again at 1845 and recorded which fruits were moved at night and during the day. In this way, I compared the distances fruits were moved by nocturnal and diurnal rodents.

Statistical Analysis

I used the Mann-Whitney U test to compare differences in cover between the two sites and distances fruits were moved between sites in each of the two years. T-tests were used to compare the average number of fruits taken per station at the two sites.

Results

Vegetation

Vegetation differed between the two sites. Both sites had a similar cover of Joshua trees, but CF cover was dominated by live shrubs (*Lycium andersonii*, *Purshia tridentata* var. *glandulosa*) and bare ground (Table 1). In contrast, pinyon pine (*Pinus monophylla*) cover at LV averaged 23.5% whereas pinyons were absent in the transects at CF. The understory of LV was dominated by herb cover, collapsed dead shrubs and downed Joshua trees (Table 1). Due to the low cover of live shrubs, the understory of LV was considerably more open than CF.

Table 1. Plant species cover, herbaceous cover, bare ground cover, dead shrub cover and litter cover for Cactus Flats and Lone Valley. Values are mean cover \pm 1 SD. Cover comparisons were made using Mann-Whitney U for 26 transects at each site.

Plant species	Cactus Flats	Lone Valley	Statistical significance
<i>Yucca brevifolia</i>	8.1 (9.8)	11.1 (17.0)	$P = 0.95$
<i>Pinus monophylla</i>	0.0	23.5 (20.4)	$P < 0.001$
<i>Lycium andersonii</i>	12.7 (10.9)	0.0	$P < 0.001$
<i>Purshia tridentata</i> var. <i>glandulosa</i>	10.0 (13.0)	3.1 (6.2)	$P = 0.053$
<i>Artemisia tridentata</i>	2.7 (6.7)	1.9 (4.9)	$P = 0.91$
<i>Fremontodendron californicum</i>	4.2 (12.7)	0.0	$P = 0.08$
Herbaceous	0.8 (2.7)	18.1 (15.8)	$P < 0.001$
Litter	0.0	7.7 (11.4)	$P < 0.001$
Dead shrubs	11.2 (14.8)	18.5 (11.2)	$P < 0.02$
Bare ground	45.0 (19.2)	26.1 (21.7)	$P < 0.001$

Camera Trapping

There were 80 photographs of animals at fruit stations and 407 photographs at seed stations. White-tailed antelope squirrels comprised the highest percentage (61.3%) of photographs at fruit stations followed by kangaroo rats (16.3%) (Table 2). Kangaroo rats dominated photographs at seed stations (45.5%) followed by white-tailed antelope squirrels (16.5%). Western scrub jays (*Aphelacoma californica*) visited seed stations at LV in both years (Table 2). Although jays were active at CF, they were not photographed at seed stations in either year.

Fruit Removal and Fruit Movements

Of the total 208 fruits placed under trees (2 sites \times 2 years \times 52 trees per site), 147 (70.7%) were moved and subsequently opened, 29 (13.9%) had cut threads and the fruit was missing, 20 (9.6%) fruits were missing but the bobbin remained, 5 (2.4%) remained unopened at stations, 4 (1.9%) were moved but not opened, and 3 (1.4%) were taken into woodrat nests.

Of the 147 fruits that were moved and opened, 101 (68.7%) were taken beyond the canopy ($>$ 1.0 m) (Fig. 1). Fruit transport distances did not differ significantly between the two sites in 2013 ($Z = -1.03$, $p = 0.30$) or in 2014 ($Z = 1.64$, $p = 0.10$) (Table 3) even though the understory was more open at LV than at CF (Table 1). Of the 101 fruits moved $>$ 1.0 m, 10 (9.9%) were

Table 2. Number of photographs by species for each site and each year.

	Cactus Flats				Lone Valley			
	2013		2014		2013		2014	
	Fruits	Seeds	Fruits	Seeds	Fruits	Seeds	Fruits	Seeds
White-tailed antelope squirrel	15	18	12	30	15	16	7	3
Kangaroo rats	3	81	7	90	3	14	0	0
Pocket mice	2	25	0	8	2	20	0	4
Pinyon mouse	3	3	4	1	3	18	1	54
Merriam's chipmunk	0	0	2	0	0	0	0	0
California ground squirrel	0	0	1	1	0	0	0	0
Western scrub jay	0	0	0	0	0	2	0	19

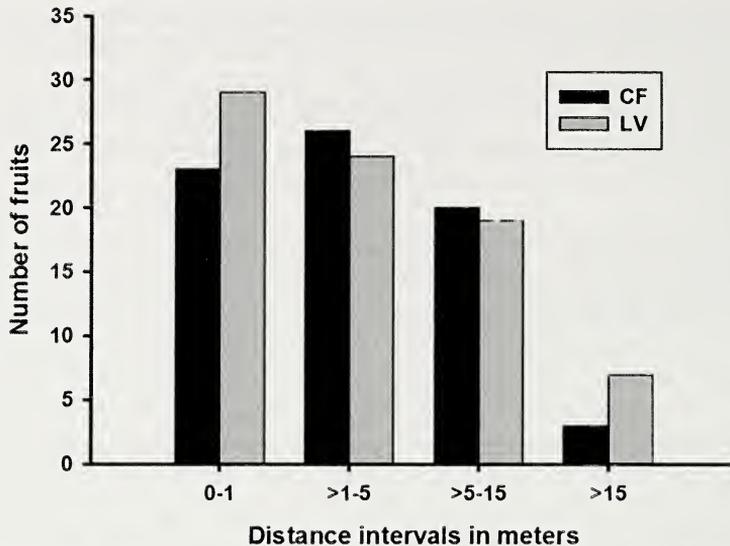


Fig. 1. The number of spool-and-line fruits dispersed by distance intervals at each site. Distances were pooled for 2013 and 2014. CF is Cactus Flats and LV is Lone Valley.

taken beyond 15 m (Fig. 1): the maximum distance a fruit was moved was 46.9 m, and the mean maximum distance was 21.2 m ($n = 4$).

At CF in 2014 the mean (\pm SD) distance fruits were moved by white-tailed antelope squirrels during the day ($8.3 \text{ m} \pm 7.8 \text{ m}$, $n = 7$) did not differ significantly ($Z = 0.95$, $p = 0.36$) from the mean distance of those moved at night by kangaroo rats ($4.5 \text{ m} \pm 3.4$, $n = 11$). The maximum distance a fruit was carried in the day was 25 m while the maximum distance at night was 11.3 m.

White-Tailed Antelope Squirrels

White-tailed antelope squirrels removed the highest percentages of fruits in late morning (0900-1200) and early afternoon (1200-1500) (Fig. 2). In 2013 at CF they moved 22% of the 50 fruits from 6 stations, and at LV 76% of fruits from 8 stations (Table 4). The average number of fruits taken per station at LV was significantly higher ($t = 2.59$, $df = 11$, $p < 0.001$) than the average number taken at CF in 2013 (Table 4). In 2014 at CF, white-tailed antelope squirrels moved 42% of the 50 fruits from 5 stations, and 52% were moved from 6 stations at LV. The average number of fruits taken per station did not differ significantly ($t = 0.03$, $df = 9$, $p = 0.97$) between the two sites (Table 4). In the two years, five fruits were dismantled by white-tailed antelope squirrels at CF while just one was opened at LV.

Table 3. Fruit dispersal distances ($> 1.0 \text{ m}$) at CF and LV for 2013 and 2014. Values are means $\pm 1 \text{ SD}$ (sample sizes).

Site	Year	Distance (m)
Cactus Flats	2013	6.1 ± 4.82 (32)
	2014	4.8 ± 4.7 (19)
Lone Valley	2013	7.6 ± 5.9 (34)
	2014	6.8 ± 6.2 (14)

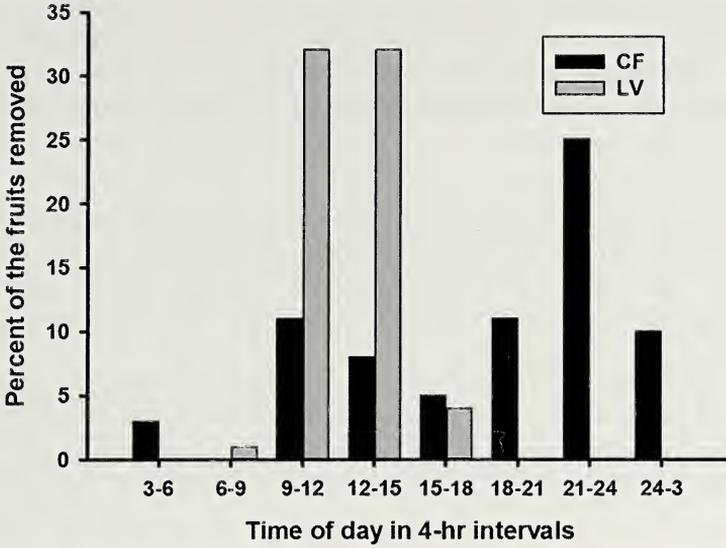


Fig. 2. Percent of the fruits removed at the two sites in four-hour intervals over 24 hours. Values are for the two years combined. CF is Cactus Flats and LV is Lone Valley.

In the two years at both sites, white-tailed antelope squirrels visited a total of 8 seed stations, far fewer than the 25 stations visited for fruits. In 2013 at CF squirrels left 25–75% of the seeds in dishes, although they removed nearly all the seeds in 2014. At LV they collected all the seeds in both years. Nocturnal rodents invariably collected the small number of seeds not taken by white-tailed antelope squirrels during the day.

Kangaroo Rats

Kangaroo rats visited stations between 1800 and 0600 hours and removed the highest percentage of fruits just before midnight (Fig. 2). At CF kangaroo rats removed 41% of the 50 fruits from 5 stations in 2013, and 59% of the fruits from 8 stations in 2014 (Table 4). In contrast, they only harvested fruits at LV in 2013 and were not photographed removing fruits or seeds at LV in 2014.

Table 4. Fruit removal from camera-trapping stations by white-tailed antelope squirrels and kangaroo rats. Fruits removed per station are means ± 1 SD with sample sizes in parentheses. The percentages in parentheses are for 50 fruits (5 fruits × 10 stations). CF is Cactus Flats and LV is Lone Valley.

Site	Year	Stations visited	# Fruits taken (%)	# Fruits removed per station
White-tailed antelope squirrels				
CF	2013	6	11 (22%)	1.8 ± 0.9 (6)
	2014	5	21 (42%)	4.2 ± 1.6 (5)
LV	2013	8	38 (76%)	4.4 ± 0.8 (8)
	2014	6	26 (52%)	4.2 ± 1.3 (6)
Kangaroo rats				
CF	2013	5	17 (34%)	3.2 ± 1.3 (5)
	2014	6	24 (48%)	4.4 ± 1.3 (6)

At CF kangaroo rats collected seeds at 5 stations in 2013 and at 8 stations in 2014. They collected nearly all of the seeds after multiple visits. Pinyon mice, and sometimes pocket mice, harvested the few seeds not taken by kangaroo rats. In 2013 at LV, kangaroo rats gathered seeds from 2 stations; seeds not taken by kangaroo rats were collected by pinyon mice at LV.

Pocket Mice and Pinyon Mice

Pocket mice dismantled 7 fruits at 2 stations at LV in 2014, and three fruits were removed. Pinyon mice opened 7 fruits at 2 stations at CF and removed 3 fruits. They collected seeds from 5 stations at LV and from 3 stations at CF in the two years. Like pocket mice, pinyon mice harvested more seeds than fruits. In the two years, they took seeds from two stations at CF and from 7 stations at LV.

A pair of western scrub jays was present at each site in both years. At LV they visited 4 stations in two years and removed all the seeds from two stations, one in 2013 and one in 2014 (Table 2). At each site they carried one spool-and-line fruit a short distance (< 3 m). A California ground squirrel (*Otospermophilus beecheyi*) briefly visited seed dishes at one CF station in 2014.

Discussion

White-tailed antelope squirrels moved fallen Joshua tree fruits at both sites in both years and visited more fruits (63%) than seed stations (20%). Similarly, in southern Nevada, white-tailed antelope squirrels visited just 13% of the 23 stations supplied with Joshua tree seeds (Waitman et al. 2012). Although fruits collected at CF in 2013 were large (averaging 4.3 cm in diameter and 6.6 cm in length) and weighed 14 g (dry), white-tailed antelope squirrels (100-110 g) easily carried them from the stations. Moreover, because the average fruit contained 95 undamaged seeds, they efficiently moved numerous seeds in a single visit, as opposed to the multiple visits required to carry loose seeds (Table 2). Because shrub cover was low at LV compared to CF, I expected fruits to be moved greater distances but there was no significant difference in mean distance between the two sites. At CF, rodents carried fruits through dense shrubs stems (especially *Lycium*) into openings and through additional shrub patches before opening them. As a result, threads often traced highly circuitous routes. At LV rodents frequently hid fruits next to downed Joshua tree stems near the location of deployment. Fruits carried greater distances often were taken in straight lines.

In addition to collecting fallen fruits, white-tailed antelope squirrels are agile climbers (Zemba and Gall 1980; Waitman et al. 2012, Borchert and DeFalco 2016). In both years at CF squirrels removed or opened 24 - 28% of canopy fruits (Borchert and DeFalco 2016). For example, in 2014 I placed a sample of spool-and-line fruits in eight trees. Camera trapping showed white-tailed antelope squirrels climbed trees and dismantled fruits but they also carried the spool-and-line fruits to the ground, where they dispersed them in the same way they dispersed fallen fruits in this study (unpublished data).

The results of this and other studies suggest white-tailed antelope squirrels are likely keystone seed dispersers in deserts of the arid West because it is a relatively large rodent, is an excellent climber, possesses cheek pouches for seed storage, and scatterhoards seeds (Beck and Vander Wall 2010). Furthermore, it is widely distributed across eight states (Belk and Smith 1991), and is relatively abundant (Clark 2010; Borchert and DeFalco 2016). In southern Nevada, Bradley (1968) found seeds of 11 shrubs and six forbs and grasses in the cheek pouches of white-tailed antelope squirrels including *Y. brevifolia*, *Y. baccata* and *Y. schidigera*. Squirrels also collected and dispersed fallen *Pinus monophylla* seeds (Hollander and Vander Wall 2004) and the fruits of *Prunus andersonii* (Beck and Vander Wall 2010). White-tailed antelope squirrels

removed 75% of the fruits in the canopies of *P. andersonii* as well as the seeds and fruits of *Y. brevifolia* (Zembal and Gall 1980; Waitman et al. 2012; Borchert and DeFalco 2016). At CF I camera-trapped squirrels removing both seeds and fruits of *Fremontodendron californica* from beneath shrubs. In 2015 at LV, they were camera-trapped removing and opening fruits of *Opuntia phaeacantha* (0.5-1 m in height). White-tailed antelope squirrels likely climb other desert shrub and tree species to obtain fruits and seeds.

Although Merriam's kangaroo rats, the most common kangaroo rat species on the two sites (Borchert and DeFalco 2016), are considerably smaller (40-50 g) than white-tailed antelope squirrels, they also carried fruits, sometimes tens of meters. Kangaroo rats are well-known seed dispersers (Longland 1994; Jenkins et al. 1995; Jenkins and Breck 1998; Longland et al. 2001, Waitman et al. 2012; Longland and Ostoja 2013) but carrying large fruits has not been described for this species. I photographed this species removing fruits at CF in both years but not at LV where they gathered seeds in one (2013) of the two years. Still, the maximum length of camera trapping a station was only 72-hours, so fruit mobilization by kangaroo rats also may have occurred at LV but was not photographed. They readily collected loose seeds from dishes and typically visited stations multiple times (Table 2) until all but a few seeds remained.

Because nearly all kangaroo rat species do not climb, fruit removal by these species is likely confined to years of high fruit production when they fall to the ground (Borchert and DeFalco 2016). Nevertheless, even in years of low fruit production, white-tailed antelope squirrels consume or disperse canopy fruits before they reach the ground. Therefore, in low production years non-climbing rodents only have access to seeds in unopened fruits on the ground abandoned by white-tailed antelope squirrels or to seeds left in dismantled fruits. Pinyon mice and pocket mice removed small numbers of fruits and were likely more important in dispersing seeds than fruits.

Fruit removal by kangaroo rats and white-tailed antelope squirrels increases the known dispersal distance of Joshua tree seeds. The weighted average distance of primary dispersal by rodents in southern Nevada was 13.7 m, and the weighted averaged distance of secondary dispersal was 12.1 m, summing to 25.8 m (Vander Wall et al. 2006). In this study the weighted average fruit movement distance for the two sites was 6.4 m which, when added to 25.8 m for seed dispersal sums to 32.2 m, an increase of almost 25%. In this study the mean maximum distance for fruits was 21.2 m, which when summed with Vander Wall et al.'s (2006) estimate of maximum primary seed dispersal of 30.0 m totals 51.2 m, or a 41% increase over estimate when only seed dispersal is considered. Nevertheless, 51.2 m does not include the mean maximum distance for secondary seed dispersal.

Fruit movement in this study demonstrates how a thorough examination of disperser behavior may reveal unobserved steps in the dispersal process, steps that increase seed dispersal distances. For example, seed dispersal by agoutis (*Dasyprocta* sp.) illustrates how dispersal distances can increase once its foraging behavior was fully examined. In central Amazonia agoutis cached single Brazil nuts (*Bertholletia excelsa*) within 10 m of the source (Tuck Haugaasen et al. 2010). However, a second study of Brazil nut dispersal (Tuck Haugaasen et al. 2012) showed agoutis carried unopened fruits an average of 20.8 m before they scatterhoarded nuts another 4 m. Fruit and seed dispersal together averaged 29.2 m. Thus, studies that rely only on marked seeds may underestimate dispersal distances, especially for plant species with indehiscent fruits (Tuck Haugaasen et al. 2012). In the Sonoran and Mojave deserts of California at least 22 plant species are serotinous like *Y. brevifolia* (Martinez-Berdeja and Ezcurra 2015) suggesting that other species may benefit from the fruit-carrying behavior of *Ammospermophilus* and *Dipodomys*.

If fruit mobilization is a widespread phenomenon in Joshua trees, seed dispersal distances for this arborescent succulent may be greater if, in addition to fruit displacement, seeds are

re-cached multiple times. Repeated re-caching increases dispersal distances because the cumulative distance from the source increases with each successive re-cache (Vander Wall and Joyner 1999, Roth and Vander Wall 2005, Perea et al. 2011, Jansen et al. 2012, Wang et al. 2014). Jansen et al. (2010) followed the dispersal of a large-seeded palm (*Astrocaryum standleyanum*) by Central American agoutis (*Dasyprocta punctata*). After caching and re-caching palm seeds numerous times (up to 36), agoutis moved 33% of the seed > 100 m and some seeds up to 900 m. Vander Wall et al. (2006) recorded secondary caching of Joshua tree seeds, but tertiary or quaternary caching could further increase seed dispersal distances.

Several researchers have suggested the limited seed dispersal of Joshua tree as a major impediment to its migration in response to climate change (Cole et al. 2011; Barrows and Murphy-Mariscal 2012). Nevertheless, it is important to note that the expansion of a species outside its current range in response to climate change depends on factors besides seed dispersal including: seed availability (Kroiss et al. 2015), abundance of germination microsites (Kroiss et al. 2015), interspecific plant competition (Urban et al. 2013; Tomiolo et al. 2015), interactions with obligate pollinators (Blatrix et al. 2013), disturbance (Serra-Diaz et al. 2015; Springer et al. 2015) and landscape heterogeneity (Chardon et al. 2015; Serra-Diaz et al. 2016).

California scrub jays are well-documented long distance dispersers of the acorns of California oaks (Pesendorfer et al. 2016) and were present at both sites. In this study scrub jays dispersed small numbers (< 3) of fruits short distances (< 2 m) although the threat may have discouraged them from flying far. They also were photographed collecting loose seeds at LV. Nevertheless, even when fruits were abundant, I did not observe them opening fruits to extract seeds. The role of scrub jays in the dispersal of Joshua trees remains unresolved. Even if they did not open fruits, it is possible that they collect and disperse seeds from partially open fruits attached to the panicle or dismantled fruits on the ground.

Acknowledgements

I wish to thank Lesley DeFalco and Stephen Vander Wall for commenting on the draft manuscript. I thank the two anonymous reviewers of the manuscript for their helpful suggestions and edits.

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Status of the Endangered Chorro Creek Bog Thistle *Cirsium fontinale* var. *obispoense* (Asteraceae) in Coastal Central California

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Abstract.—Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* (Asteraceae) is a biennial or short-lived perennial plant up to 2 m tall that occurs only in San Luis Obispo County, west of the outer coast ranges. It was listed as endangered under the California Endangered Species Act in 1993 and the U.S. Endangered Species Act in 1994. Chorro Creek bog thistle is a serpentine endemic, occupying perennial seeps and springs in serpentine soil and rock in western San Luis Obispo County from north of San Simeon Creek to south of the city of San Luis Obispo. At federal listing in 1994 Chorro Creek bog thistle was known from nine occurrences (one of these presumed extirpated) and with an estimate of <3,000 individuals. In 2016 the conservation status of Chorro Creek bog thistle is substantially improved because of an increased number of known occurrences along with an increased number of occurrences that are protected. Only two of nine known occurrences were protected in 1994, whereas 10 of 21 occurrences are protected in 2016. There are many other locations with habitat that have not been searched, in particular on private land. It is highly likely that additional unknown occurrences exist in San Luis Obispo County, and possibly also in Monterey County to the north and Santa Barbara County to the south. In consideration of the available information, we conclude that Chorro Creek bog thistle is still endangered. However, when using the international standards of IUCN, we assign the category data deficient because of the limitations of our data.

The fountain thistle *Cirsium fontinale* is a plant in the aster and sunflower family (Asteraceae) with a known geographic range extending from San Francisco County southward to San Luis Obispo County in western California. Three varieties are recognized (Baldwin et al. 2012): Crystal Springs fountain thistle *C. fontinale* var. *fontinale*, Mount Hamilton fountain thistle *C. fontinale* var. *campylon*, and Chorro Creek bog thistle *C. fontinale* var. *obispoense*. Crystal Springs fountain thistle occurs west of San Francisco Bay in San Mateo and San Francisco Counties. Mount Hamilton fountain thistle occurs south and east of San Francisco Bay in Alameda, Santa Clara and Stanislaus Counties. Chorro Creek bog thistle occurs only in San Luis Obispo County, 176 km south of the nearest occurrence of Mount Hamilton fountain thistle (USFWS 2014). Chorro Creek bog thistle and Crystal Springs fountain thistle were listed as endangered under the U.S. Endangered Species Act in 1994 and 1995 (U.S. Fish and Wildlife Service [USFWS] 1994, 1995), respectively, and also under the California Endangered Species Act in 1993 and 1979 (California Department of Fish and Wildlife [CDFW] 2016b), respectively. Mount Hamilton fountain thistle is not listed.

Chorro Creek bog thistle is a biennial or short-lived perennial plant up to 2 m tall. Its spiny leaves have glandular hairs on the upper and lower surfaces, and its flowers are white, pink or lavender with a drooping posture. Each flower head produces ≈73 seeds (mean), which are up to 4 mm long (Turner and Herr 1996) and with a pappus (set of bristles) that aids dispersal.

Chorro Creek bog thistle is diagnosed from the other two varieties by combination of several morphological characteristics of the stem, leaf, inflorescence, flower and fruit. Baldwin et al. (2012) provide complete descriptions of the three varieties.

At federal listing in 1994, Chorro Creek bog thistle was known from nine occurrences, one of these presumed extirpated, and with an estimate of <3,000 individuals. Identified threats were cattle grazing (trampling, herbivory), proposed development, water diversions, road maintenance, inadequate legal protection, stochastic events (in particular drought), and invasive (non-native) plants (USFWS 1994). Two occurrences were protected. USFWS (2014) reviewed the conservation status of Chorro Creek bog thistle (19 known occurrences) and recommended no change in the legal listing status. Our purpose is to review and enhance the knowledge of Chorro Creek bog thistle, in particular its distribution, ecology, abundance, threats, management and conservation status in 2016.

Materials and Methods

We surveyed and censused many occurrences of the Chorro Creek bog thistle in San Luis Obispo County from 2009 to 2016, and we found five previously unknown occurrences. We counted and estimated (after gaining experience by counting) the number of plants in each colony (a spatial group of separate individuals) and occurrence that we observed. We considered reports of the USFWS and CDFW, data in the California Natural Diversity Database (CDFW 2016a), and personal communications from other biologists who also observed the species. Using all available information, we summarize the knowledge of Chorro Creek bog thistle in 2016. We consider a location with the species as a separate occurrence if it is >0.4 km from the nearest occurrence (California Department of Fish and Game 2011). The stated distances and the stated numbers of plants are approximates. Elevations were determined using tools in Google Earth. Latin and common names of plants follow Baldwin et al. (2012), with exception of *C. fontinale* var. *obispoense* for which we use Chorro Creek bog thistle rather than San Luis Obispo fountain thistle. Areas (ha) of properties are from records of the County of San Luis Obispo and the City of San Luis Obispo. We provide the relevant and available details for each occurrence in Appendix 1. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the USFWS.

Results and Discussion

Chorro Creek bog thistle (Fig. 1) is a serpentine endemic (Safford et al. 2005; Baldwin et al. 2012.), occupying perennial seeps and springs in serpentine soil and rock in western San Luis Obispo County (Fig. 2). Although we conducted no soil tests, each of the 21 known occurrences is on or adjacent to a serpentine deposit according to geologic maps (Wieggers 2009, 2010) and/or geologist David Chipping (USFWS 2014). Serpentine soil and rock are characterized by low calcium to magnesium ratios, and with calcium at significantly lower levels relative to surrounding areas. In addition, serpentine soil and rock frequently contain elevated levels of heavy metals (e.g. iron, nickel, chromium, cobalt), which are toxic to most other plants, and they are often deficient in essential plant nutrients (e.g. nitrogen, potassium, phosphorus; Brady et al. 2005). Because of their ultramafic origin, which in western San Luis Obispo County is associated with tectonics and subduction (Wieggers 2009, 2010), serpentine substrates are often steep outcrops (Brady et al. 2005). Accordingly, we report that Chorro Creek bog thistle occur mostly on slopes (Fig. 3).

Chorro Creek bog thistle typically live 2 or 3 years. The plant forms a rosette of leaves in the first year that can attain up to 0.9 m diameter. Stalk development begins during February



Fig. 1. Flower head of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* on Camp San Luis Obispo (occurrence 3), San Luis Obispo County, California (12 May 2005). Photo courtesy of David Magney, Ojai, California.

or March of the second year, and it continues to May or early June with some plants attaining >2 m height, although 0.5 to 1.0 m is most common. Flowering generally occurs during May to mid-June, and with some branched stalks bearing >25 flowers. After flowering and setting seed, the stems turn brown, lean to one side and eventually fall. Some living plants may persist into a third year if sufficient energy reserves remain. Under drought conditions, stalk development is less vigorous, and the buds and flower heads develop substantially faster, but fewer actually flower. This is likely an adaptive strategy for quickly producing seeds before the substrate dries. At several occurrences with dense, invasive grasses (e.g. Laguna Lake Natural Reserve), Chorro Creek bog thistle are often unable to spread their leaves into rosettes. Instead, they appear like spiny romaine lettuce, most of which flower and set seed. As the invasive grasses die back in midsummer, the leaves of the plant fall outward and form a carpet around its center, which suppresses future growth of grasses. This results in a substantial amount of seed germination within the circle of old leaves during the following year and with little seed germination beyond the circle (Chipping in USFWS 2014).

In 2016, we report that the 21 known occurrences of Chorro Creek bog thistle comprise a geographic range of 253 km², extending from north of San Simeon Creek (35.63087, -121.06535) to south of the city of San Luis Obispo (35.239909, -120.699012; 58 km distance). The 12 occurrences (10-21) identified since listing have expanded the geographic range by 69% (150 km²), and six of these occurrences are protected while six are not: protected — four occurrences (14, 15, 16, 17) on public lands owned by the City of San Luis Obispo, one

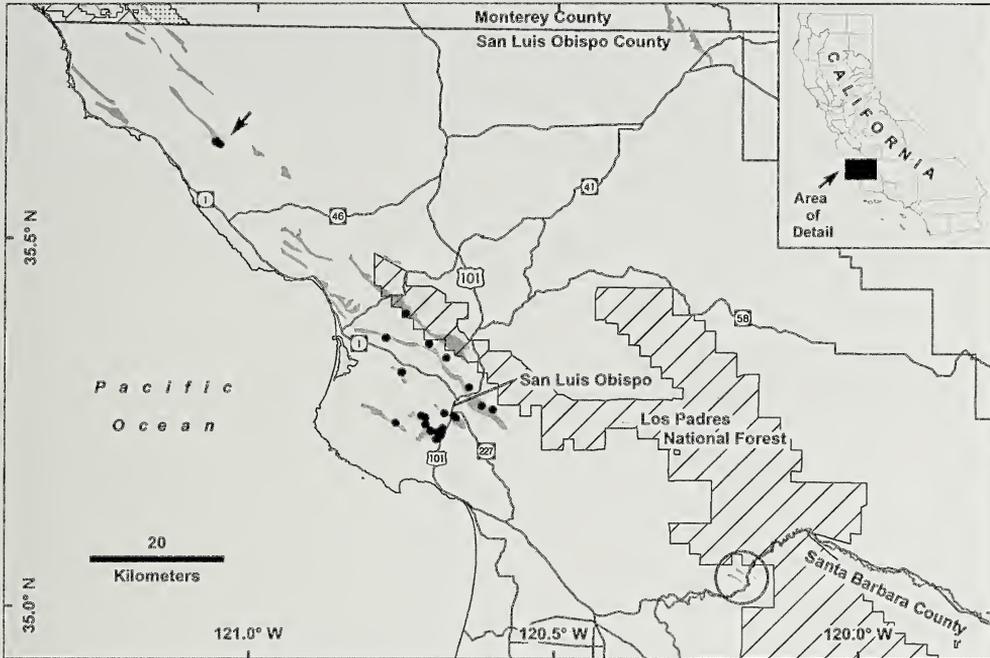


Fig. 2. The known geographic distribution of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* in western San Luis Obispo County, California. Black dots indicate the 21 known occurrences, and the arrow indicates the two northernmost occurrences near San Simeon Creek. The plant inhabits perennial seeps and springs in serpentine soil and rock (gray shaded areas). We recommend searching for additional occurrences in San Luis Obispo County in the serpentine soil and rock indicated in this map. See also Fig. 4 and 5.

occurrence (13) on private property with a conservation easement to the City of San Luis Obispo, and one occurrence (12) legally protected on private property with an open-space easement to the County of San Luis Obispo; not protected — one occurrence (19) on a property owned by the California Army National Guard, four occurrences (10, 18, 20, 21) on five private properties, and a “lost” occurrence (11; precise location unknown) likely on a private property. Also, it is highly likely that additional unknown colonies and occurrences exist in San Luis Obispo County, and possibly in Monterey County to the north and in Santa Barbara County to the south (Figures 2, 4 and 5), and in particular on private property.

All known occurrences of Chorro Creek bog thistle are west of the outer coast ranges, and at 38 to 380 m elevation. Occurrences 1 and 18 (San Simeon Creek watershed; Table 1) are the northernmost occurrences, and with a distance of 37 km from the nearest occurrence (9, tributary of San Bernardo Creek in Chorro Creek watershed) to the southwest. The other 18 occurrences are clustered in three primary watersheds (Chorro Creek, San Luis Obispo Creek, Los Osos Creek), with a maximum distance of 5.8 km between any two occurrences. Occurrence 2 at Laguna Lake Natural Reserve in the city of San Luis Obispo comprises multiple colonies at 14 seeps. Occurrence 13 near Loma Bonita Drive is 1.6 km to the southeast on the same serpentine outcrop in the city of San Luis Obispo. Occurrences 4, 5, 7, 8, 14, 15, 16 and 21 are associated with a serpentine outcrop in Irish Hills southwest of the city of San Luis Obispo, and occurrence 12 near Serpentine Lane is also in Irish Hills on a separate serpentine outcrop 4.1 km west of these occurrences. Occurrences 10, 11 and 17 occupy a serpentine outcrop



Fig. 3. Occurrence 13 of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* in the central part of the city of San Luis Obispo (the urban area), San Luis Obispo County, California (16 December 2011). This occurrence comprises a single colony at a seep on private property that is used for cattle grazing. Trampling is not a threat because the plants are on a steep, rocky slope. The landowner granted a conservation easement to the City of San Luis Obispo (the local government).

immediately north and east of the city of San Luis Obispo. Occurrences 3, 6, 9, 19 and 20 are associated with serpentine outcrops in foothills north and west of the city of San Luis Obispo.

Most occurrences (1, 2, 3, 4, 6, 8, 9, 12, 14, 17, 18, 19, 20) of Chorro Creek bog thistle are comprised of multiple colonies. Information on abundance is limited because recent census data are lacking for 11 occurrences (Table 2). Although 10 occurrences were censused during the past 5 y (2012 to 2016), four were last censused in 1993, one in 1987, one in 1997, one in 2001, and one in 2007. Only occurrence 3 on Camp San Luis Obispo was subject to formal and regular monitoring (1994 to 2008). Currently, 14 occurrences are subject to informal and irregular monitoring, and seven occurrences have no monitoring. Six occurrences were reported to comprise >1,000 plants at particular points in time: occurrence 1 (San Simeon Creek), >1,000 plants in 1984 (CDFW 2016a); occurrence 2 (Laguna Lake Natural Reserve), most recently 1,718 plants in 2016 (pers. obs.); occurrence 3 (Camp San Luis Obispo), most recently 1,782 plants in 2014 (Kevin Merk, San Luis Obispo, pers. comm. 2016); occurrence 6 (El Chorro Biological Reserve), most recently 2,200 plants in 1993 (Chipping in USFWS 2014); occurrence 10 (Mioossi Creek), >1,000 plants in 1997 (CDFW 2016a); and occurrence 12 (near Serpentine Lane), >4,000 plants in 2001 (CDFW 2016a). The greatest estimates for the 15 other occurrences range from 3 to 800 plants.

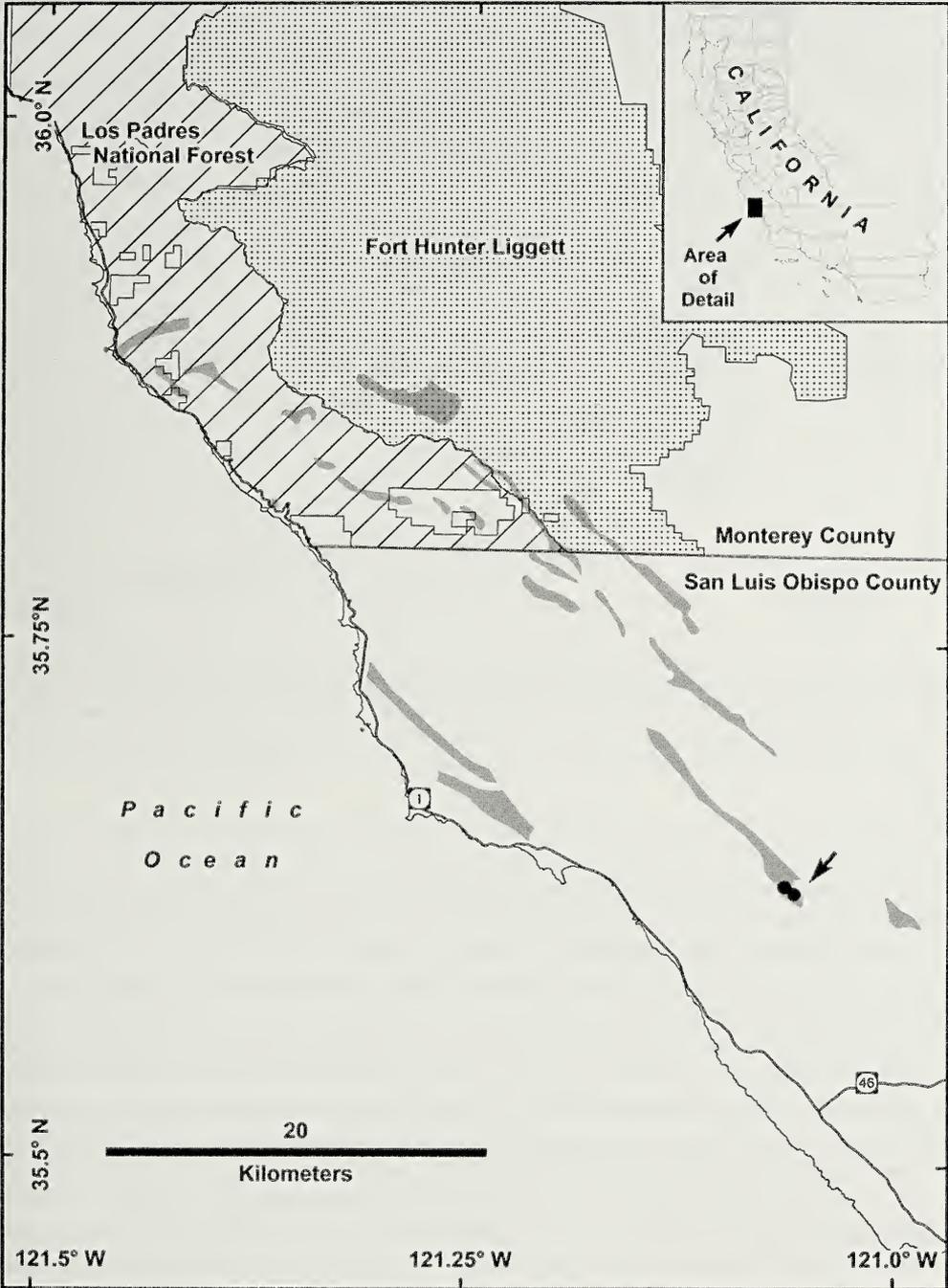


Fig. 4. Serpentine soil and rock (gray shaded areas) in Monterey County, California. Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* inhabits perennial seeps and springs in serpentine soil and rock in western San Luis Obispo County, as currently known. The arrow indicates the two northernmost occurrences near San Simeon Creek. We recommend searching for additional occurrences in Monterey County in potential habitat in the serpentine soil and rock indicated in this map. See also Fig. 2 and 5.

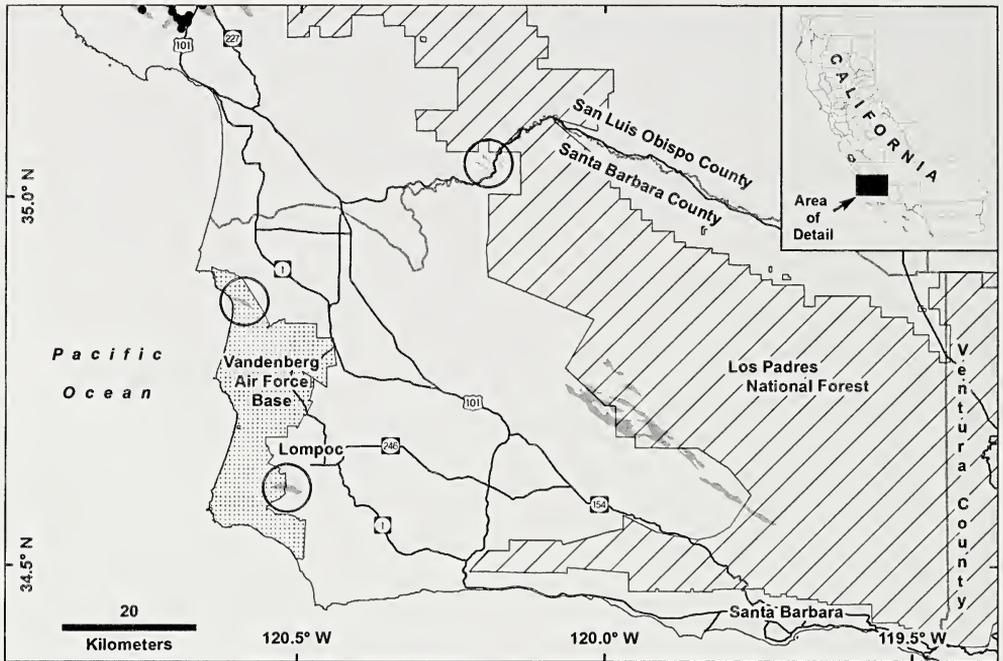


Fig. 5. Serpentine soil and rock (gray shaded areas) in Santa Barbara County, California. Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* inhabits perennial seeps and springs in serpentine soil and rock in western San Luis Obispo County, as currently known. The group of black dots (upper left) indicates the southernmost occurrences in the vicinity of the city of San Luis Obispo. We recommend searching for additional occurrences in Santa Barbara County in potential habitat in the serpentine soil and rock indicated in this map. See also Fig. 2 and 4.

Since 1968 the Eurasian flower-head weevil *Rhinocyllus conicus* has been introduced at multiple locations in North America (Herr 2004) as a biocontrol agent for invasive thistles *Carduus* and *Silybum*, including San Luis Obispo County in 1973 (Goeden et al. 1985) and in particular Camp San Luis Obispo in the early 1980's (California Army National Guard in USFWS 2014). The adult weevils congregate on young thistles in early spring to feed and mate. They lay eggs (mean 192 eggs per female) on developing flower heads into which the subsequent larvae tunnel and feed on. Pupation occurs in the flower head, with adults emerging in midsummer. One generation per year is produced (Zwolfer and Harris 1984). By 2005 the weevil occurred in 26 states and Canada (Dodge 2005), with multiple reports of feeding also on native thistle *Cirsium* (Turner et al. 1987). This weevil was reported feeding on Chorro Creek bog thistle at three occurrences: San Simeon Creek (Herr 2004; Chipping in USFWS 2014;), Laguna Lake Natural Reserve (Herr 2004), and Camp San Luis Obispo (California Army National Guard in USFWS 2014). At San Simeon Creek, 28% of the flower heads were infested throughout the growing season (42% in July 1995), and with 27% (mean) of seeds destroyed in the infested flower heads. Seed loss was 8% of total seed set at the study site (Turner and Herr 1996; Herr 2004; John Herr, U.S. Dept. Agric., Albany, Calif., pers. comm. 2012). Turner and Herr (1996) reported a phenological difference in peak egg laying of the weevil in relation to flower head production of Chorro Creek bog thistle. At Laguna Lake Natural Reserve (Herr 2004), infestation rates were 32% in May (1996) and 5% in July (1995). Magney (USFWS 2014) saw no weevils at Camp San Luis Obispo in September (2005), although the California Army

Table 1. Distribution of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* in western San Luis Obispo County, California: the primary and secondary watersheds of the 21 known occurrences.

Primary watershed	Secondary watershed	Occurrence
San Simeon Creek		1
	North Fork (some colonies)	<u>18</u>
Chorro Creek		3
		19
	Pennington Creek	6
	San Bernardo Creek	9
	San Luisito Creek	<u>20</u>
San Luis Obispo Creek		13
		21
	Prefumo Creek	2 Laguna Lake
		4
		5
	Froom Creek	7
		8
		14
		15
		16
	Miossi Creek	10
	Reservoir Canyon Creek	11
		<u>17</u>
Los Osos Creek		12

National Guard (USFWS 2014) subsequently observed weevils feeding on Chorro Creek bog thistle in 2012. Lutz (2013) saw no evidence of weevils at Reservoir Canyon Natural Reserve (occurrence 11). In sum, we consider the Eurasian flower-head weevil a threat because it was seasonally destroying a substantial number of seeds at the occurrence where studied.

Regarding cattle grazing in and near the habitat of Chorro Creek bog thistle, herbivory and trampling are the two obvious issues. At Camp San Luis Obispo, cattle grazing caused a substantial decrease in established plants and a substantial increase in juvenile plants (Mardesich and Laughlin in USFW 2014). Along with Chipping (Calif. Polytech. St. Univ., pers. comm. 2012) and Nancy Siepel (Calif. Dept. Transport., San Luis Obispo, pers. comm. 2012) who observed cattle grazing in the vicinity of Chorro Creek bog thistle, we consider the effects of herbivory as minor and not a threat because the spiny plants are generally unpalatable (USFWS 1998). However, trampling can severely damage established plants, especially when water is limited and cattle congregate at the water. In addition, cattle can damage the structure of the riparian area or seep (e.g., damage to streambank by hooves, damage to soil by defecation; Swanson et al. 2015).

The USFWS (2014) identified stochastic events as a threat to Chorro Creek bog thistle. Species with small populations are vulnerable to extinction by stochastic events (Shaffer 1981, Ricklefs 2008). This means that environmental or demographic chance or randomness can cause the population size to fluctuate, and in small populations the fluctuations are more likely to include zero. The 21 occurrences of Chorro Creek bog thistle exist as a metapopulation in a relatively small geographic area (271 km²), and with only six occurrences reported to contain >1,000 individuals. Therefore, we consider stochastic events an ongoing threat.

Table 2. Approximate numbers of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* in the 21 known occurrences in western San Luis Obispo County, California.

Year	Occurrence																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2016		1718 ^f					0 ^f	250 ^f													
2015			1782 ^g										≥200 ^f	3 ^f	86 ^f						
2014																	689 ^c				
2013																					
2012							0 ^f	800 ^f													
2011		1400 ^f			150 ^f								500 ^f	500 ^f							300 ^f
2008			1872 ^c																		
2007			762 ^c	>200 ^a																	
2006		1750 ^j	1565 ^c																		
2005			1843 ^h										300 ^a								
2004			1759 ^h																		
2003			643 ^a																		
2002			3393 ^a																		
2001			2792 ^a																		
2000			4433 ^a																		
1999		>2000 ^a	4644 ^a																		
1998			822 ^a																		
1997			1055 ^a																		
1996			1782 ^a																		
1995			2871 ^a																		
1994			1845 ^a																		
1993	285 ^b	1025 ^b	250 ^c	557 ^b	70 ^b	2200 ^b		250 ^b	500 ^b												792 ^b

Table 2. Continued.

Year	Occurrence																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1992	375 ^b						10 ^b														
1989		100 ^a																			
1988	550 ^a																				
1987	<150 ^a						15 ^a	>100 ^a			25 ^k										
1986	100 ^d	1000 ^d		150 ^b	50 ^b	<1000 ^a															
1984	>1000 ^a			>100 ^a																	
1981		1000 ^a		30 ^a		<1000 ^a															

^a California Department of Fish and Wildlife (2016a).

^b Chipping (USFWS 2014).

^c Holland (USFWS 2014).

^d Friedman (USFWS 2014).

^e Lutz (2013).

^f pers. obs.

^g Merk, pers. comm. 2016.

^h Magney (USFWS 2014).

ⁱ Carter (2002).

^j Elvin (USFWS 2014).

^k Consortium of California Herbaria (USFWS 2014).

^l Waldburger, pers. comm. 2012.

^m Siepel, pers. comm. 2012.

The USFWS (2014) identified climate change as a new threat to the Chorro Creek bog thistle. The year 2015 was the warmest since record keeping began in 1880, and most of the warming occurred in the past 35 years with 15 of the 16 warmest years occurring since 2001 (Brown et al. 2016). In particular, California is becoming hotter and drier. The 3-year period from 2012 to 2014 was the hottest and driest in California in the 100-year time frame considered (Mann and Gleick 2015), and it was the most severe drought in California in the past 1,200 y (Griffin and Anchukaitis 2014). Species with small geographic ranges are more vulnerable to climate change (e.g., Foden et al. 2013), and of particular concern are associated extreme weather events. Because Chorro Creek bog thistle is restricted to seeps and springs in serpentine soil and rock, a severe drought could reduce or eliminate its specialized habitat. In consideration of the life history traits used by Anacker et al. (2013), the plant is moderately to highly vulnerable to climate change because of its relatively small geographic range and its soil and habitat specificity.

The conservation status of Chorro Creek bog thistle has improved substantially since listing in 1994 because of an increased number of known occurrences along with an increased number of occurrences that are protected (Table 3). Only two of nine known occurrences were protected in 1994, whereas 10 of 21 occurrences are protected in 2016. Six of the protected occurrences (2, 4, 14, 15, 16, 17) are in natural reserves owned by the City of San Luis Obispo. One protected occurrence (6) is in a biological reserve owned by California Polytechnic State University. One protected occurrence (13) is on a private property with a conservation easement to the City of San Luis Obispo. Also, one occurrence (3) is protected on Camp San Luis Obispo because the California Army National Guard consults with the USFWS regarding its activities as required under the U.S. Endangered Species Act. These nine occurrences are on properties that range in size from 65 to 2,271 ha. In addition, one occurrence (12) is on private property (8.1 ha) with an open-space easement (0.8 ha) to the County of San Luis Obispo, however, we do not know the conservation status or immediate threats.

Regarding the non-protected occurrences of Chorro Creek bog thistle, occurrences 1 and 20 are each on two private properties, and with one of each pair of landowners wishing to conserve the plants. Occurrence 5 is in a roadside drainage ditch above underground lines, and it is at risk by road and utility maintenance. Occurrence 7 (along Froom Creek just below mouth of Froom Canyon) is on private property and near existing development, and potentially at risk from future channelization and residential development. We saw no plants here in 2012 and 2016. Occurrence 8 is on the adjacent private property and at risk from existing development and potentially future residential development. Occurrence 19 is on a property owned by the California Army National Guard, and it is at risk from nearby agriculture by California Polytechnic State University. However, we are communicating with the California Army National Guard and California Polytechnic State University in an effort to gain protection for this occurrence. Occurrence 21 (southeast Irish Hills) is on private property and is presently safe because of its location on a steep rocky slope and away from development. Four additional occurrences (9, 10, 11, 18) are on private properties for which we do not know the conservation status or immediate threats. Because there are potentially many locations with habitat on private properties and public lands that have not been searched, it is highly likely that additional occurrences exist in San Luis Obispo County, and possibly also in Monterey and Santa Barbara Counties.

The U.S. Endangered Species Act and the California Endangered Species Act have little ability to protect the Chorro Creek bog thistle on private property. Invasive plants are a threat or potential threat at five occurrences and native plants at two occurrences. Stochastic events remain a threat to all occurrences. The Eurasian flower-head weevil and climate change with severe drought are newly identified threats. In consideration of the available information, we conclude that Chorro Creek bog thistle is still endangered. However, when using the international

Table 3. Conservation status of the 21 known occurrences of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* in western San Luis Obispo County, California, in 2016.

Occurrence	Location	Landowner	Protected	Status	Immediate threats
1	San Simeon Creek	two private	no	unknown	water extraction, cattle trampling, Eurasian flower-head weevil ^f
2	Laguna Lake Natural Reserve	City of San Luis Obispo	yes	robust, healthy 2016 ^a	invasive plant species
3	tributary of Chorro Creek, Camp San Luis Obispo	Calif. Army Natl. Guard	yes	reduced number 2014 ^b	native and invasive plant species
4	four tributaries of Prefumo Creek in Irish Hills Natural Reserve	City of San Luis Obispo	yes	healthy 2012 ^a	none
5	drainage ditch along Prefumo Canyon Rd and tributary of Prefumo Creek	County of San Luis Obispo	no	at risk ^e	road and utility maintenance
6	East Fork of Pennington Creek, El Chorro Biological Reserve	private	no	healthy 2012 ^c	none
7	Froom Creek just below mouth of Froom Canyon	Calif. Polytech. St. Univ. private	yes	no plants 2012 ^a 2016 ^a	near + potential development
8	Seep and tributary of Froom Creek	private	no	at risk 2016 ^a	near + potential development
9	tributary of San Bernardo Creek	private	no	unknown	unknown
10	slope above Miossi Creek	private	no	unknown	unknown
11	near Reservoir Canyon Creek and Hampton Creek, location unknown	likely private	no	unknown	unknown
12	near Serpentine Lane, W of Prefumo Canyon	private	legally yes	unknown	unknown
13	slope near Loma Bonita Drive in the city of San Luis Obispo	private w/conservation easement to City of San Luis Obispo	yes	reduced number 2015 ^a	none

Table 3. Continued.

Occurrence	Location	Landowner	Protected	Status	Immediate threats
14	tributary of Froom Creek near old mine, central part of Irish Hills Natural Reserve	City of San Luis Obispo	yes	healthy 2011 ^a	potentially, invasive plant species
15	tributary of Froom Creek, central part of Irish Hills Natural Reserve	City of San Luis Obispo	yes	at risk 2015 ^a	few plants $n = 3$
16	Poppy Spring, central part of Irish Hills Natural Reserve	City of San Luis Obispo	yes	healthy 2015 ^a	none
17	Reservoir Canyon Natural Reserve	City of San Luis Obispo	yes	healthy 2013 ^d	shade from native trees
18	Cambria Mine near San Simeon Creek	private	no	unknown	development
19	tributary of and along Chorro Creek, SW of confluence with Pennington Creek	Calif. Army Natl. Guard	no	at risk 2015 ^a	nearby agriculture
20	seep and spring along a tributary of San Luisito Creek	two private	no	unknown	potentially, invasive plant species ^{e, g}
21	tributary of San Luis Obispo Creek	private	no	healthy 2012 ^a	potentially, invasive plant species

^a pers. obs.^b Merk, pers. comm. 2016.^c Chipping, pers. comm. 2012.^d Lutz (2013).^e Siepel, pers. comm. 2012.^f California Department of Fish and Wildlife (2016a).^g Schweitzer, pers. comm. 2015.

standards of IUCN (2012, 2014), we assign the category data deficient because of the limitations of our data.

Recommendations

We make the following recommendations to help conserve the Chorro Creek bog thistle. The USFWS with its partners should survey and census all 21 occurrences during one calendar year, and special efforts should be made for gaining access to the relevant private properties (in particular those with occurrences 1, 9, 10, 11, 12 and 18). The relevant land managers and biologists should monitor the occurrences for invasive plants, and the invasive plants should be removed promptly. The relevant land managers should strictly control and monitor any cattle grazing in the habitat of Chorro Creek bog thistle. Strictly-controlled cattle grazing could possibly benefit Chorro Creek bog thistle by reducing other vegetation (invasive and native) and by providing favorable sites for germination of its seeds. However, uncontrolled cattle grazing in the habitat could cause severe damage. The relevant land managers and biologists should be aware that the Eurasian flower-head weevil is a threat to Chorro Creek bog thistle, and they should monitor for and report this invasive insect to USFWS and the San Luis Obispo County Department of Agriculture. Additional occurrences of Chorro Creek bog thistle likely exist in San Luis Obispo County, and possibly also in Monterey and Santa Barbara Counties. Searches should be conducted in habitat with serpentine soil and rock in San Luis Obispo, Monterey and Santa Barbara Counties (Figures 2, 4 and 5).

Acknowledgements

We thank the following persons for the information that they provided: LynneDee Althouse, David Chipping, John Herr, Robert Hill, Nic Huber, Tyler Lutz, David Keil, Jody Olson, Freddy Otte, Brad Penkala, Jake Schweitzer, Nancy Siepel and Peter Waldburger. Angela Chapman, Douglass Cooper, Kristi Lazar, Roger Root and Connie Rutherford engaged in valuable discussion. Kirk Waln produced the maps.

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Appendix 1

The 21 known occurrences of Chorro Creek bog thistle *Cirsium fontinale* var. *obispoense* in western San Luis Obispo County, California.

Occurrence 1. 35.62530, -121.05453 (CDFW 2016a); 107 m. This occurrence is in springs at the foot of a serpentine landslide in the San Simeon Creek watershed (Chipping in USFWS 2014) in northwest San Luis Obispo County. It is along San Simeon Creek, 0.3 km by road (San Simeon Creek Road) downstream of the confluence of the North and South Forks and with the colonies on two private properties (Chipping in USFWS 2014; 12 ha; 5 ha). We viewed images of the properties using Google Earth (dated 2 April 2015) on 23 August 2016, and both were partially developed: one with an avocado farm and clearings, and the other with a house, garage, carport and barn. Both properties are zoned for agriculture. More than 1,000 plants were reported in 1984, and 285 plants in 1993, which is the most recent information (Chipping in USFWS 2014). In the early 1990's the Nature Conservancy assisted the private landowners with fencing to protect some colonies, and one private landowner is protecting the plants under a voluntary agreement (CDFW 2016a). Road maintenance, water diversions and cattle were potential threats in the 1990's (Chipping in USFWS 2014; Wikler and Morey in USFWS 2014). The CDFW (2016a) record states that introduced weevils are heavily infesting the flower heads, water is being extracted from the seep, and cattle are trampling the plants. Chipping (USFWS 2014) referred to this site as the San Simeon "Bianchi" complex. Up until 2014 this occurrence also included six sites to the west on the adjacent private property, which subsequently became occurrence 18 (Cambria Mine near San Simeon Creek; CDFW 2016a) because the separating distance is >0.4 km.

Occurrence 2. 35.266453, -120.682235; 35.266862, -120.682499; 35.266922, -120.682589; 35.267021, -120.682793; 35.267148, -120.683091; 35.268814, -120.684751; 35.269886, -120.683706; 35.270353, -120.684086; 35.270658, -120.683897; 53 to 85 m (pers. obs.). This occurrence is in Laguna Lake Natural Reserve (152 ha) on land owned by the City of San Luis Obispo. The Chorro Creek bog thistle are in 14 seeps spanning 635 m on a hillslope 340 m east of Laguna Lake. Most colonies are enclosed by fences, although some colonies are expanding beyond the fences and into the landscape that is subject to controlled grazing by horses and cattle for fuel reduction. Some fences are collapsing in 2016. More than 2,000 plants were recorded in 1999 (CDFW 2016a). Although the serpentine substrate is not conducive for most invasive species (Harrison et al. 2006), pampas grass *Cortaderia* became established in the habitat (and competed with Chorro Creek bog thistle), which we and the County of San Luis Obispo removed in 2010. In 2016 and after 4 y of drought, the occurrence appeared healthy and robust with 1,716 plants. However, at one particular seep (lower down the hillslope and with more soil) the colony had disappeared, and invasive species (bull thistle *Cirsium vulgare*, rye grass *Festuca*, vervain *Verbena*) predominated. We identify this seep (35.268814, -120.684751) for a needed restoration effort. Otherwise, invasive plants were under control in 2016 and with a notable absence of pampas grass. This occurrence is protected. We and the City of San Luis Obispo monitor irregularly and informally.

Occurrence 3. 35.34302, -120.68178; 244 m (CDFW 2016a). This occurrence is at seeps adjacent to a tributary of Chorro Creek (0.8 km northeast of Chorro Reservoir) on Camp San Luis Obispo (2271 ha), which is owned by the California Army National Guard. It is protected because the California Army National Guard consults with the USFWS (e.g., USFWS 1997, 2015) regarding its actions on the installation that may affect federally listed species, as required by the U.S. Endangered Species Act. The California Army National Guard conducted annual and formal monitoring from 1994 to 2008, then irregular and informal monitoring from 2009 to 2013, and then formal monitoring in 2014 (Merk, pers. comm. 2016). This occurrence has experienced substantial annual variation in numbers of reported plants, ranging from 250 (1993) to 4,644 (1999) individuals (Holland in USFWS 2014, CDFW 2016a). We suspect that the lowest numbers reflect relatively less survey effort. Merk (pers. comm. 2016) recorded 1,782 plants in 2014 during the most recent census. The USFWS (1997) issued a biological opinion for controlled cattle grazing because several species of native (spikerush *Eleocharis macrostachya*, bulrush *Scirpus*) and invasive plants (rye grass) were becoming dense in the habitat. Although controlled grazing from 15 April to 14 May 1998 removed <5% of vegetation, the total number of Chorro Creek bog thistle increased 68% following the disturbance. Juvenile plants increased 727% (Mardesich and Laughlin in USFWS 2014), but established plants decreased. Later in 2006, Magney (USFWS 2014) reported that invasive prickly sow thistle *Sonchus asper* had invaded the habitat and was being removed. In 2012 the occurrence was threatened by dense vegetation in and near the habitat, including native (salt grass *Distichlis spicata*, spikerush) and invasive species (purple star-thistle *Centaurea calcitrapa*, bristly ox-tongue *Helminthotheca echioides*, prickly sow thistle; Jody Olson, Camp San Luis Obispo, pers. comm. 2012). In 2014, Merk (pers. comm. 2016) observed excessive accumulation of thatch, especially from native species (spikerush, sneezeweed, *Helenium* sp., salt grass). To manage thatch and potentially competitive plants in and near the habitat, the California Army National Guard (USFWS 2015) intends to conduct controlled cattle grazing during fall from 1 September to 15 October. Cattle grazing could possibly benefit Chorro Creek bog thistle by reducing potentially competitive plants in and near the habitat, and by providing favorable

sites for germination of seeds (Bransfield in USFWS 2014; California Army National Guard in USFWS 2014). However, cattle grazing in and near the habitat must be strictly controlled and monitored to achieve benefits and to minimize adverse effects (USFWS 2015).

Occurrence 4. 72 to 96 m (pers. obs.). This occurrence is at the northern edge of Irish Hills Natural Reserve (south of Prefumo Canyon Road; 381 ha), which is owned by the City of San Luis Obispo. The colonies are in four tributaries of Prefumo Creek: a waterfall (35.263558, -120.715975) and the creek above for ≥ 500 m (Chipping in USFWS 2014), two nearby gullies to the southeast (150 m and 250 m distance; 5.263206, -120.714431; 35.26265, -120.713492), and another creek further to the southeast along the Bog Thistle Nature Trail (1 km southeast of the waterfall; 35.261344, -120.711639; pers. obs.). Chipping (USFWS 2014) recorded 557 plants in 1993. This occurrence is protected. We and the City of San Luis Obispo monitor irregularly and informally. In addition, the City of San Luis Obispo has placed interpretive signs along the nature trail, and it conducts guided hikes that include viewing the Chorro Creek bog thistle in its habitat.

Occurrence 5. 35.264806, -120.721775; 88 m (pers. obs.). This occurrence is 547 m northwest of the waterfall in occurrence 4. The plants are mostly in the drainage ditch along the south side of Prefumo Canyon Road, which is owned by the County of San Luis Obispo, and also in a steep tributary of Prefumo Creek on the adjacent private land (42 ha). Additional colonies may exist further upstream along the precipitous, rocky slope, which is covered with dense chaparral vegetation. Numbers of reported plants were 150 in 2011 (pers. obs.), and previously 70 in 1993, and 50 in 1986 (Chipping in USFWS 2014). In 2011 a sign among the plants in the drainage ditch identified underground lines (pers. obs.). The plants in the drainage ditch are threatened by road and utility maintenance. Although this occurrence is not protected, the County of San Luis Obispo intends to manage in consideration of the endangered plants (Kate Ballantyne, County of San Luis Obispo, pers. comm. 2016). We monitor irregularly and informally.

Occurrence 6. 35.36213, -120.70998; 335 m (CDFW 2016a). This occurrence is along the east fork of Pennington Creek in the El Chorro Biological Reserve (81 ha), which is owned by California Polytechnic State University. It is 1.0 to 1.4 km west of Whiskey Spring, which is near the headwaters of Pennington Creek. In 2012 the occurrence was in "good shape" (Chipping, pers. comm. 2012). Numbers of reported plants were 2,200 in 1993 (Chipping in USFWS 2014), and <1,000 in 1986 and 1981 (CDFW 2016a). This occurrence is protected from cattle grazing, development, water diversions and road maintenance. California Polytechnic State University monitors irregularly and informally.

Occurrence 7. 35.24805, -120.68683 (Chipping in CDFW 2016a; pers. obs.); 38 m. This occurrence is along Froom Creek just below the mouth of Froom Canyon on flat land on one private property (14 ha). It is adjacent to and east of Irish Hills Natural Reserve. CDFW (2016a) has a record of 15 plants in 1987, and Chipping (USFWS 2014) reported 10 plants in 1992. We saw no plants in 2012 and 2016, however, we have seen scattered individuals upstream. The landscape here is especially dry and without a perennial seep or spring. We viewed images of the property using Google Earth (dated 2 April 2015) on 23 August 2016. At least six buildings occupy the property, and it is greatly disturbed by vehicles including bulldozers and graders. The stream bed is next to a dirt road. The property is zoned for commercial retail and agriculture, and the City of San Luis Obispo is considering annexation of the property for residential development.

Occurrence 8. 39 to 64 m; (pers. obs.). This occurrence is at a seep and two tributaries of Froom Creek on one private property (30 ha) adjacent to and east of Irish Hills Natural Reserve. Chipping (USFWS 2014) recorded 250 plants at three locations in 1993, which he referred to as Froom Ranch South, Froom Ranch North Spring and Froom Ranch Gully Confluence. In 2016 we observed 50 plants at Froom Ranch South (35.242601, -120.688929), 200 plants at Froom Ranch North Spring (35.243755, -120.689998) and 0 plants at Froom Ranch Gully Confluence (35.244093, -120.687286). Previously in 2012 we observed 500, 300 and 0 plants, respectively, at the three sites. We viewed images of the property using Google Earth (dated 2 April 2015) on 23 August 2016. Although the property is undeveloped, the location of Froom Ranch South is 54 m downslope of a dirt road and a building on the adjacent private property. The property with occurrence 8 and the adjacent private property are zoned for agriculture and as rural lands. The City of San Luis Obispo is considering annexation of the property with occurrence 8 for residential development.

Occurrence 9. 35.40309, -120.74930; 302 m (Chipping in CDFW 2016a). This occurrence is at seeps and springs along a tributary of San Bernardo Creek on one private property (297 ha), 1.6 to 2.1 km southwest of Cerro Alto Peak. The Chorro Creek bog thistle are in bogs near an inactive, open-pit chromite mine and other excavations. Chipping (USFWS 2014) is the primary source of information, who recorded 500 plants and heavy grazing in the bogs. We viewed images of the property using Google Earth (dated 2 April 2015) on 26 August 2016, and it was mostly undeveloped with exception of mined areas (10%). The property is zoned for agriculture. Based on similar geology and landscape, Chipping (USFWS 2014) surmised that additional occurrences likely

exist nearby to the east, including a “probable site” on two private properties 1.3 km to the southeast along a tributary of San Bernardo Creek.

Occurrence 10. 35.30310, -120.64356; 171 m (CDFW 2016a). This occurrence is in seeps and springs on a northeast slope above Miossi Creek (a tributary of San Luis Obispo Creek) on one private property (141 ha) that is 0.4 km east of California Polytechnic State University and 0.8 km north of Cuesta Canyon County Park. The primary source of information is a report dated 1997 (CDFW 2016a) with observation of >1,000 plants along with cattle in the habitat. We viewed images of the property using Google Earth (dated 2 April 2015) on 20 September 2016, and it was undeveloped. The property is zoned for agriculture. Based upon apparently similar landscape features, there is high potential for additional colonies and occurrences on the adjacent and nearby undeveloped properties.

Occurrence 11. ≈35.27573, -120.60414 (CDFW 2016a). This “lost” occurrence is known from only two specimens collected in 1987 (Consortium of California Herbaria in USFWS 2014): “on S slope of Reservoir Canyon, 1/8 mi SE of Reservoir and Hampton Cr. junction, Reservoir Rd., 1 mi. N of San Luis Obispo off Hwy 101. 280 m.” Approximately 25 individuals were observed in a spring on a north facing slope in 1987. Nic Huber (USFWS, Ventura, pers. comm. 2011) searched for the occurrence in the Reservoir Canyon Natural Reserve in 2006 but without success. The collector (Brad Penkala, Santa Barbara, pers. comm. 2012) was unable to provide any additional details. We suspect the occurrence is likely on a private property.

Occurrence 12. 35.256738, -120.765841; 318 m (our determination). This occurrence is at three seeps on one private property (8.1 ha; LynneDee Althouse, Paso Robles, pers. comm. 2012 [CDFW 2016a is incorrect] near the junction of Serpentine Lane and Prefumo Canyon Road (6 km west of the city of San Luis Obispo), with a small open-space easement (three parcels, 0.8 ha) to the County of San Luis Obispo. Specifically, the occurrence is north of benchmark 1336, north side of Prefumo Canyon Road, and west of Prefumo Canyon. It is the only occurrence in the Los Osos Creek watershed and at its headwaters. Some colonies are on the north part of the property near the boundary with the adjacent private property (Althouse, pers. comm. 2012), and some colonies are on the southern half of the property according to records of the County of San Luis Obispo. We viewed images of the property using Google Earth (dated 2 April 2015) on 20 September 2016. It was mostly undeveloped, and with one building in its southwest corner. We suspect that Chorro Creek bog thistle likely occurs also on the two private properties immediately north and east because of seemingly similar landform and geology. The property with the occurrence is zoned as rural lands. Althouse (CDFW 2016a) recorded >4,000 plants in 2001, and the occurrence has not been visited by a biologist since then.

Occurrence 13. 35.26189, -120.66533; 75 m (pers. obs.). This occurrence is on one private property (16 ha), 60 m northeast of Loma Bonita Drive in the central part of the city of San Luis Obispo (the urban area) with a conservation easement to the City of San Luis Obispo (the local government). Although the property is used for cattle grazing, trampling is not a threat because the plants are at a seep on a steep, rocky slope. We and the City of San Luis Obispo monitor irregularly and informally, and it has authority to conduct management activities. We found this occurrence in 2005 at which time we estimated 300 plants. In 2011 the colonies appeared healthy with 500 plants. In 2015 and after several years of drought we observed at least 200 plants, which is a reduced number. Chipping (USFWS 2014) searched this area in 1993 and saw no Chorro Creek bog thistle. We viewed images of the property using Google Earth (dated 2 April 2015) on 25 August 2016, and it was undeveloped with exception of communication facilities on 0.5 ha. The property is zoned for conservation/open space. It is west of and adjacent to South Hills Open Space (20 ha), which is owned by the City of San Luis Obispo, and another private property with an open-space easement (29 ha) to the City of San Luis Obispo. The combined total area for conservation/open space of the three contiguous properties is 65 ha. This occurrence is protected.

Occurrence 14. 35.24435, -120.70457; 267 m (pers. obs.). We found this occurrence along a tributary of Froom Creek near an old mine in the central part of Irish Hills Natural Reserve, and we estimated at least 500 plants in 2011. Pampas grass was in the habitat, which we removed in 2010 and 2011. We and the City of San Luis Obispo monitor irregularly and informally. This occurrence is protected.

Occurrence 15. 35.25044, -120.70581; 189 m (pers. obs.). We found this very small occurrence in 2011 along a tributary of Froom Creek (120 m south of Froom Creek;) in the central part of Irish Hills Natural Reserve. In 2015 we counted three plants along a 200-m stretch of stream with little to no soil and debris in the stream bed likely due to large stormflows. The location is in steep terrain on a hillslope with dense chaparral vegetation. We suspect that a source population exists nearby upstream where the hillslope is less steep, and this should be investigated. We and the City of San Luis Obispo monitor irregularly and informally. This occurrence is protected.

Occurrence 16. 35.25262, -120.71388; 207 m (pers. obs.). We found this occurrence in 2011 at Poppy Spring (50 m from Froom Creek) in the central part of Irish Hills Natural Reserve. In 2015 and after several years of

drought, we estimated 86 plants and at which time the occupied area comprised 13 m x 0.5 m along a small stretch of stream. In 2011 we estimated 63 plants. We and the City of San Luis Obispo monitor irregularly and informally. This occurrence is protected.

Occurrence 17. 35.278584, -120.621042; 318 to 380 m (Lutz 2013). This occurrence is on a north-facing slope in a steep canyon immediately east of the city of San Luis Obispo in Reservoir Canyon Natural Reserve (210 ha). It comprises four colonies in a seep and tributary of Reservoir Canyon Creek (Carter 2002, Lutz 2013), which is a tributary of San Luis Obispo Creek. Carter (2002) observed 270 plants in 2001 and a patchy overstory (California bay *Umbellularia californica*, Brewer's willow *Salix breweri*). Lutz (2013) counted 689 plants in 2013 along 131 m of stream with an extensive overstory (Brewer's willow, California bay, California coffee berry *Frangula californica*, toyon *Heteromeles arbutifolia*) and shade that appeared to be adversely impacting Chorro Creek bog thistle. He trimmed part of the overstory, and the City of San Luis Obispo is monitoring for effects. This occurrence is protected.

Occurrence 18. 239 to 313 m (Chipping in USFWS 2014). This occurrence (Cambria Mine near San Simeon Creek) was separated out of occurrence 1 in 2014. It is 1.1 km west of occurrence 1 on an adjacent private property (167 ha) in a rural area zoned for agriculture. The occurrence is based upon field survey records in 1988, 1989, 1991 (CDFW 2016a) and 1993 (Chipping in USFWS 2014). Chipping (USFWS 2014) reported 792 plants in 1993 and colonies at six sites in springs and bogs, which he designated as A Upper Spring Site (35.629594, -121.065679), B North Roadside Spring (35.630918, -121.066138), C Stock Pond (35.634259, -121.062773), D Stock Reservoir (35.633339, -121.062740), E Big Seep (35.633228, -121.064237), and F Cambria Mine Site (35.628308, -121.066337). Chipping (USFWS 2014) observed cattle in the habitat, and also weevils in the flowers of Chorro Creek bog thistle that he suspected were Eurasian flower-head weevils. We viewed images of the property using Google Earth (dated 2 April 2015) on 23 August 2016. Although the property is mostly undeveloped, it contains a house, a garage, a barn, four parking areas, an orchard and two areas for livestock. Further, D Stock Reservoir has been replaced with a lake (0.4 ha), and it appears likely that the colonies reported here no longer exist. This occurrence is at risk from development, water diversions and cattle grazing.

Occurrence 19. 35.324094, -120.753916; 63 m (Peter Waldburger, Camp San Luis Obispo, pers. comm. 2012). This occurrence is at a seep and tributary of Chorro Creek on a hillslope immediately southwest of the confluence of Pennington Creek and Chorro Creek. The property (18 ha) is owned by the California Army National Guard as part of Camp San Luis Obispo, and it is zoned for agriculture. In January 2012 the colony comprised > 100 plants and appeared "healthy" when viewed across a fence line and with no evidence of cattle grazing (Waldburger, pers. comm. 2012). David Keil (Calif. Polytech. St. Univ., pers. comm. 2012) previously observed Chorro Creek bog thistle in this vicinity along Chorro Creek. Chipping (USFWS 2014) had searched this area in 1993 and found no plants. We viewed images of the property with the occurrence using Google Earth (dated 2 April 2015) on 8 August 2016, and it was mostly undeveloped. However, a small area (0.6 ha) of the property on the north side of Chorro Creek had row crops, and likewise the adjacent property to the north that is owned by California Polytechnic State University. This agriculture is in close proximity to any Chorro Creek bog thistle in Chorro Creek and is not compatible with its survival. We are communicating with the California Army National Guard and California Polytechnic State University and seeking protection for this occurrence.

Occurrence 20. 35.370836, -120.779905; 103 m (Siepel, pers. comm. 2012); 35.372239, -120.778903; 125 m (Jake Schweitzer, Berkeley, Calif., pers. comm. 2016). This occurrence is at a seep and along a tributary of San Luisito Creek on two private properties (129 ha; 150 ha) that are north of Chorro Creek and in its watershed. Siepel (pers. comm. 2012) visited one property several times and estimated 200 individuals in July 2011. She stated that the plants there were "doing well" and appeared stable at the perennial seep and spring. The landowners identified the plants on this property in 2000. They wish to conserve the plants, and they monitor irregularly and informally. Light, controlled cattle grazing occurs in and near the habitat, which appears to benefit Chorro Creek bog thistle by reducing invasive plants (Siepel, pers. comm. 2012). Invasive species included poison hemlock *Conium maculatum* in the habitat and purple star-thistle nearby, which the landowners were attempting to eradicate. Schweitzer (pers. comm. 2016) visited the other property twice in 2015. He estimated 40 Chorro Creek bog thistle along 14 m of stream, and he also observed plants across the fence line on the adjacent property. Schweitzer saw evidence of light cattle grazing in the habitat, and he removed several bull thistle that were growing in the habitat. We viewed images of the two properties using Google Earth (dated 2 April 2015) on 20 September 2016, and they were undeveloped. The two groups of Chorro Creek bog thistle are separated by 170 m. The two properties are zoned for agriculture. The Chorro Creek bog thistle on the former property are presently safe from destructive cattle grazing, development, water diversions and road maintenance, while the plants on the latter property are at risk. Based upon apparently similar landscape features, there is high potential for additional colonies and occurrences on the nearby undeveloped properties.

Occurrence 21. 35.239909, -120.699012; 179 m (pers. obs.). We found this occurrence at a seep and small stream (a tributary of San Luis Obispo Creek) on a steep hillslope on private property (89 ha) between Irish Hills Natural Reserve and Johnson Ranch Open Space. We recorded 300 plants in 2012. Although cattle grazing occurs on the property, the location with Chorro Creek bog thistle is not accessible. Pampas grass was growing near the habitat in 2012, which we and the City of San Luis Obispo removed. We are not aware of any additional threats. We viewed images of the property using Google Earth (dated 2 April 2015) on 24 August 2016, and it was undeveloped with exception of a winery (2 ha) 1.1 km downslope at the property boundary. This is the southernmost occurrence of the Chorro Creek bog thistle.

Environmental Factors Influencing Reproduction in a Temperate Marine Reef Goby, *Rhinogobiops nicholsii*, and Associated Behaviors

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Abstract.—The blackeye goby is a protogynous reef fish common to the northeastern Pacific Ocean. While this ubiquitous species has been the focus of numerous studies, there are several aspects of its reproductive ecology that are unknown. By directly quantifying reproduction from digital photographs of blackeye goby nests in the field, this study aimed to determine whether reproductive patterns were linked to 1) lunar phase or 2) ambient water temperature; and 3) whether the behavior of gobies changed when a nearby conspecific had eggs in his nest. At Santa Catalina Island, California, twenty 2.25-m² artificial reefs were established and stocked with similar numbers and size-distributions of blackeye gobies during the summers of 2012 and 2013. Photographs of nests were taken weekly for ~3 months each summer. Through analysis of photographs, incubation time was found to be more than 7 days but less than 14 days. Nests, each guarded by one male, contained an average of 8664 eggs, in an area of 43.8 cm², with 215 eggs cm⁻². Blackeye gobies laid eggs during all lunar phases and the number of eggs produced was not related to lunar phase. Reproductive output, however, was negatively correlated with water temperature, with populations on reefs that experienced cooler temperatures producing more eggs. The presence of eggs in a nest had little effect on behavior of blackeye gobies on that reef. Additional observations made outside of summer months indicated that blackeye gobies can reproduce year-round in southern California. These results suggest a reproductive strategy aimed at maximizing total reproductive output by spreading the risk of reproductive failure throughout the year rather than optimizing the timing of reproduction.

In marine animals with pelagic larvae, factors that affect recruitment of settlers into populations are typically better understood than factors that affect reproductive output. This is because it is generally easier to observe recruits than it is to observe reproduction. Thus, much of what we know about reproductive patterns of marine animals is inferred from temporal patterns of recruitment, rather than direct observations of reproduction. For example, reproductive patterns of fishes with pelagic larval phases are often reconstructed from recruitment surveys combined with otolith-based aging. This approach, however, can mask the actual patterns of reproductive output due to high and variable mortality rates during the larval phase (Carr and Syms 2006; Johnson 2008).

As an example, lunar patterns in recruitment could be driven by reproductive timing or by differences in larval delivery or survival that have a lunar basis. Synchronizing larval release with a particular lunar phase that exposes larvae to favorable environmental conditions may provide fitness benefits and has been observed in a wide array of marine taxa (Middaugh 1981; Robertson et al. 1990; Levitan et al. 2004; Fox 2013). Pelagic larvae are thought to be more conspicuous to visual predators during full moons when lunar radiance is greatest (Hobson et al.

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1981); however, photopositive larvae may swim toward the surface during full moons, avoiding predator filled reefs (Thresher 1984). Additionally, internal waves, associated with changes in tidal amplitude driven by lunar phase are thought to influence the probability and timing of larval exposure to suitable habitat and levels of intraspecific competition (Kingsford and Choat 1986; Shanks 1986; Levinton 2009).

Another factor known to affect reproduction of marine fishes is temperature (Abbott 1969; Smyder and Martin 2002; Sims et al. 2004). Generally, embryo and larval development is faster in warmer waters (Pauly and Pullin 1988; McCormick and Molony 1995), reducing incubation time (Ryland and Nichols 1975), and pelagic larval duration (O'Connor et al. 2007). Reproducing during periods of warm water can improve larval survivorship by increasing larval growth rates shifting prey out of size ranges that predators are capable of consuming (the "growth-mortality" hypothesis; Anderson 1988). Conversely, nutrient availability is often inversely related to water temperature (Dayton et al. 1998) and therefore larval growth may increase when water temperature is low and food (e.g., zooplankton) is abundant.

Alongside abiotic factors, behavior often plays a significant role in reproductive success. In fishes, demersal eggs are typically defended by the male and less often by the female or both parents (DeMartini and Sikkell 2006). Behavioral changes, such as increased aggression (i.e., nest defense) and nest maintenance, improve hatching success; however, they may occur at the cost of foraging, predatory avoidance, or further courtship. Population density (Warner and Hoffman 1980) and reproductive territoriality (Hoffman 1983) may further modify behavioral trade-offs. Thus, while altered behavior of a nesting male may improve egg survivorship, it may detract from future mating opportunities by allowing increased courtship and foraging by competing subordinate individuals.

The majority of protogynous (female-to-male sex-change) species, including the study species, exhibit a size-based social dominance hierarchy whereby dominant individuals influence the behavior of subordinate individuals (Cole 1984; Ross 1990). Specifically, alpha males dominate and socially repress growth of nearby individuals, through increased energetic expenditure and decreased foraging rates of subordinates, to maximize their competitive edge and reproductive opportunities (Helfman et al. 2009; Munday et al. 2009). Altered behavior of the alpha male, such as increased nesting behaviors at the cost of intraspecific aggression, could reduce social repression of subordinate individuals.

The blackeye goby (*Rhinogobios nicholsii*) is a protogynous fish that occurs from British Columbia, Canada to central Baja California, Mexico where it is closely associated with rocky reef habitat (Love 2011). It is common in the waters of southern California. The ubiquity and small size of this species has resulted in its widespread use as a model study species to address ecological questions (e.g. Breitburg 1987; Steele 1996; Yong and Grober 2013). While an extensive body of literature has been compiled on this species over the past 50 years, (e.g. Ebert and Turner 1962; Wiley 1973; Cole 1983), several aspects of the reproductive ecology of this species are still unknown. Ebert and Turner (1962) briefly described blackeye goby reproduction; Wiley (1973) documented food and nesting habits, morphometrics, population structure, and social behavior; Cole (1983) determined that this species exhibits protogynous hermaphroditism; and Breitburg (1987) showed that male reproductive success was limited by the availability of suitable nest sites.

Male blackeye gobies compete for territory that encompasses the territories of multiple females (Cole 1984) through a number of behavioral displays (Wiley 1973). Because blackeye gobies exhibit a size-based social dominance hierarchy, larger males tend to have greater success at acquiring and defending territories that provide opportunities to mate with nearby females (Cole 1983). Male blackeye gobies establish and defend a nest within their territory by digging a

burrow in sand under overhead rock (Ebert and Turner 1962; Wiley 1973). Females lay adhesive eggs on the rock ceiling of the burrow and the male defends and maintains the brood of eggs until they hatch (Ebert and Turner 1962). Larvae are planktonic for 40–76 days before settling to suitable reef habitat (Block 2011).

It is not known, however, whether the reproductive patterns of blackeye gobies change in response to environmental or social stimuli. We directly measured reproductive output by employing artificial nests, an approach used in studies on other small, reef-dwelling fishes (e.g. Knapp et al. 1995; Samhouri 2009; Forrester et al. 2010). We aimed to (1) determine whether blackeye gobies time reproduction with lunar phase, (2) investigate links between reproductive output and temperature, and (3) determine whether the presence of eggs in a nest influences the behavior of nearby conspecifics.

Materials and Methods

General Methods

To evaluate factors influencing reproduction in blackeye gobies, experimental populations were established on twenty rock-rubble reefs in Big Fisherman Cove, Santa Catalina Island, USA (33°26'42"N, 118°29'8"W) during the summers of 2012 and 2013 (Fig. 1A). Each reef was 2.25 m² and constructed of ~60 L of rock placed on a PVC frame lined with plastic mesh to keep the rocks from sinking into the sand. Reefs were built on a sand plane at 10–13 m depth, and were 10 m from any other reef structure to minimize movement of fish among reefs. To minimize mortality, each reef was covered with a predator exclusion cage (3.4 and 3.8-cm plastic mesh in 2012 and 2013, respectively). To investigate the influence of temperature on reproduction, six iButton temperature loggers were deployed throughout the reef array in 2013. These recorded bottom temperatures hourly from July 19 to September 13, 2013.

Each reef was stocked with a similar number, size distribution, and sex ratio of blackeye gobies as determined from surveys on natural reefs (Cole 1984, Love 2011, pers. obs.). Densities were 16 ± 4 individuals per 2.25-m² reef comprised of 5 ± 2 males, 7 ± 2 females and 4 ± 2 juveniles (mean \pm SD, $n = 20$). Gobies were collected with dip nets by SCUBA divers on natural reefs between Lion's Head Point (33°27'08"N, 118°30'05"W) and Little Geiger Cove (33°27'32"N, 118°30'59"W). Sex was determined from genital papillae, an accurate indicator of functional sex and maturity in gobiids (Cole 1983, Cole and Robertson 1988).

Reproductive Output

Reproductive output was quantified via photographs of eggs in artificial nests, using methods similar to those of Forrester et al. (2010) who studied a similar species of goby. Inverted terracotta potting saucers were used as artificial nest sites. A small opening was cut along one edge of each saucer (Fig. 2A), which provided easy access for males and promoted their use over natural rocks. Three saucers were placed on each reef (Fig. 1B). During summer months (July–September), saucers were checked weekly for the presence of broods of eggs, and all broods were digitally photographed. Additionally, from October 2013 to late March 2014, nests were checked and photographed monthly to determine if reproduction was occurring during autumn, winter, or spring.

The digital images were analyzed in Image J (Abràmoff et al. 2004) to estimate the number of eggs in each brood. Images were set to scale, total brood area was measured, and egg counts were made in five 1-cm² subsamples. Egg density appeared to be uniform, and therefore the total number of eggs in each brood was estimated as the product of the average density of eggs in the five subsamples and total brood area.

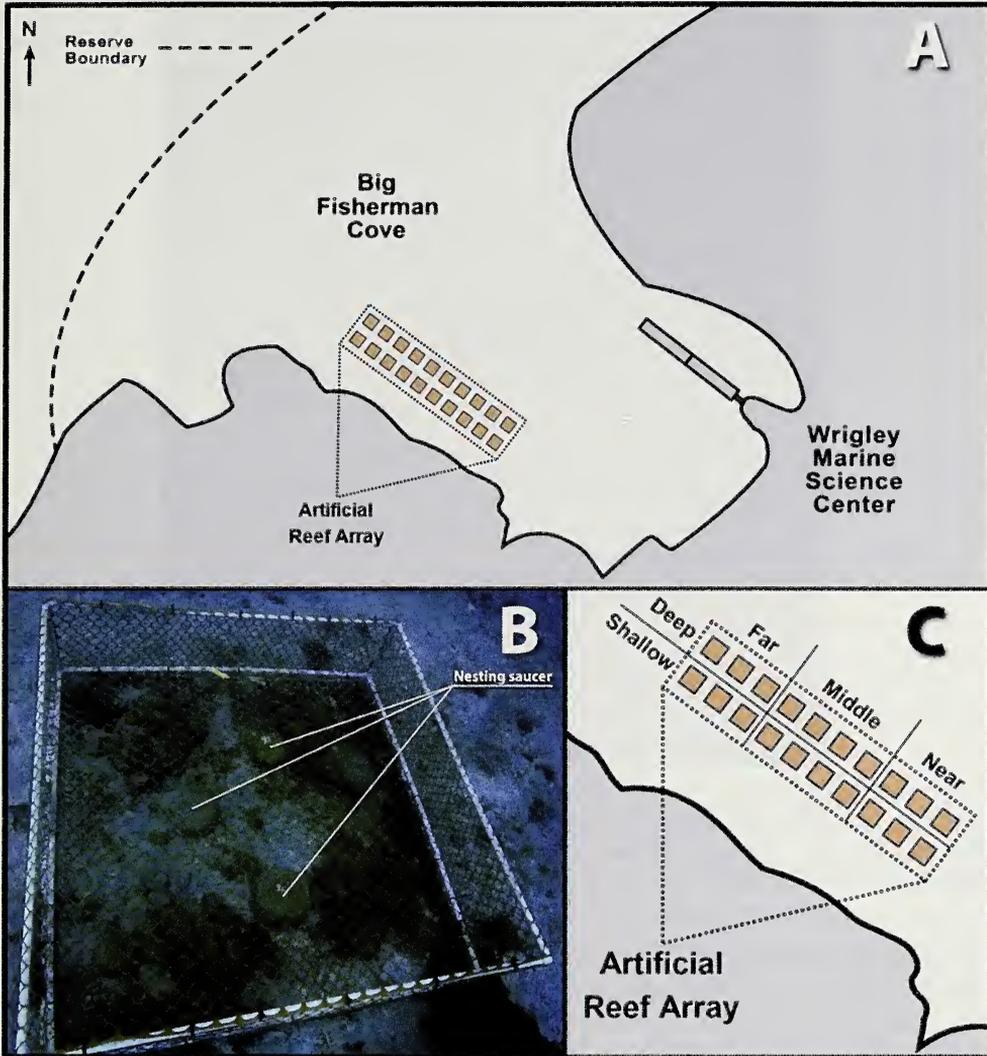


Fig. 1. Artificial reef design. A) Reefs were constructed along the southern side of Big Fisherman Cove in two parallel lines. B) Each artificial reef was composed of four interconnected sub-reefs positioned evenly within the 2.25-m² plot to maximize habitable space. Three inverted terracotta potting saucers served as artificial nests on each reef. C) Reefs were categorized by depth, shallow (~10 m) or deep (~13 m), and position relative to the back of the cove.

Behavior

Behavioral observations were conducted weekly for 7 weeks beginning on July 8, 2012 to determine if behaviors changed when broods of eggs were present on reefs. The behaviors of three classes of blackeye goby, males, females, and juveniles, were recorded. Two divers visited each reef for 6 minutes and each diver observed three fish, one in each class. The first minute of each observation period was spent identifying focal individuals and allowed fish to acclimate to diver presence, and the remaining 5 minutes were spent observing the behaviors of all three individuals. Due to the sedentary nature of the study species, it was not difficult for each diver to independently monitor three fish simultaneously. Large males were targeted

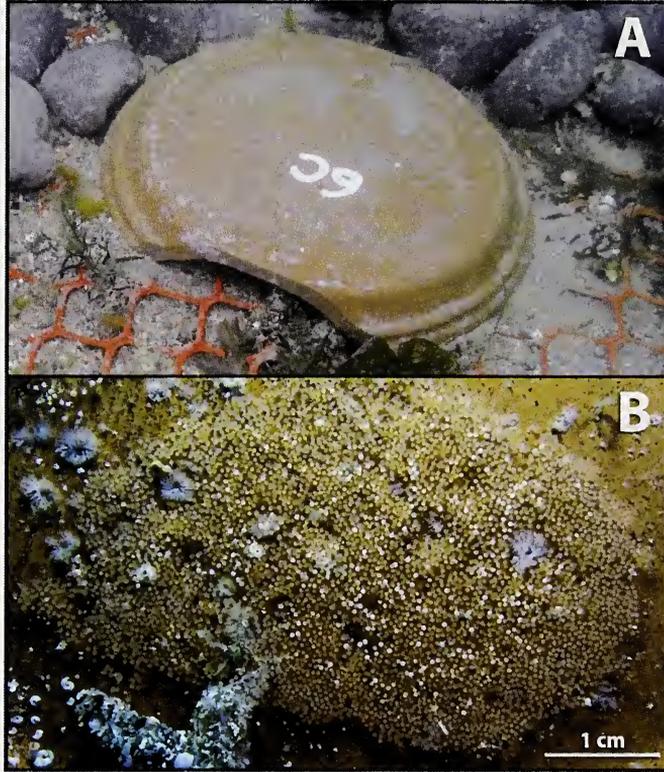


Fig. 2. Terracotta saucers were used as artificial nest sites. A) A small slot cut along one edge provided easy access for males, promoting use of artificial nests over natural rock. B) Close-up photo of a single brood of eggs on the underside of nesting saucer. Individual eggs are easily identifiable. The scattered eggs that appear white are dead, likely because they were not fertilized or succumbed to microbial infection.

because of their social dominance and influence on conspecific behavior. They were easily identified by their size [>7.5 cm standard length (SL)], black pelvic disc, and close proximity to a nesting saucer. Females were smaller (4.0–7.5 cm SL) and lacked the obvious black on their pelvic disc. Juveniles were smaller than adults (<4.0 cm SL) and were often found at reef margins, likely displaced from optimal reef habitat by territorial adults. The frequency of four focal behaviors defined by Wiley (1973; Table 1), were recorded: aggression, courtship, nesting, and foraging. Divers were unable to communicate to each other which fish they had chosen to

Table 1. Behaviors recorded, as described by Wiley (1973).

Behavior	Description
Aggression	Flaring fins and/or gaping mouth Chasing
Courtship	Flaring fins while undulating body outside nest opening Quick rushes in and out of nest
Nesting	Removing sediment or growth from inside nest Body undulations within nest entrance aerating eggs
Foraging	Short bursts into the water column picking at particles Sifting mouthfuls of sediment for infaunal organisms

observe, therefore, to avoid pseudoreplication, the average of the two divers' observations of each class were used for statistical analyses.

Temperature

Six temperature loggers (iButton thermocron, model DS1921G) were placed throughout the array of reefs to explore potential effects of temperature on reproductive output during 2013. The loggers recorded temperature every hour for nearly two months (July 19 – September 13, 2013). The iButtons were waterproofed inside a pair of male and female end caps (3/4 inch schedule 40 PVC) with Teflon thread tape and included a small dehydration packet to absorb moisture. Temperature loggers were placed in 6 evenly spaced positions relative to the back of the cove (near, middle, and far) and at different depths (shallow or deep; Fig. 1C).

Statistical Analyses

To test for any lunar pattern in blackeye goby reproduction, we used two-way, mixed-model permutational analysis of variance (PERMANOVA) to compare weekly reproductive output among the four lunar stages (new, 1st quarter, full, and 3rd quarter) over two full lunar cycles during July and August, 2012 using reefs as replicates, which were sampled repeatedly. The factors in the model were lunar stage (fixed) and reef (random). Univariate PERMANOVA was used rather than parametric ANOVA because the data were badly non-normal due to a preponderance of zeros (almost half of the observations). An a priori comparison of spring (full and new moons) and neap (first and last quarter moons) tides was conducted to test for any influence of tidal amplitude. PRIMER v6 with the PERMANOVA + add on was used for all permutational analyses.

We had too few temperature loggers to test whether reproduction on each reef was related to temperature on it, so instead, we tested whether reproductive output at reefs in the vicinity of each of 6 temperature loggers ($n = 3-4$ reefs) was correlated with differences in temperature among the 6 positions. Two-way ANOVA was used to test for (1) differences in daily bottom temperature and (2) average reproductive output per week between depths and among positions. Assumptions of normality and homogeneity of variances were met for mean daily temperature and reproductive output after square-root transformation. We tested for a correlation between reproductive output and water temperature in the 6 portions of the study area using a Spearman rank correlation, because the relationship appeared to be nonlinear. SYSTAT 13 was used for these analyses.

We tested whether blackeye goby behavior differed when a brood of eggs was present on a reef. Egg presence was based on nest photos taken 2-3 days prior to the behavioral observations. Permutational multivariate analysis of variance (PERMANOVA) was used to test for differences in behavior, with egg presence in a nest and fish class (male, female, or juvenile) as the two predictor variables and the rates of aggression, courtship, nesting, and foraging behaviors as the multivariate response variables. Rates of behaviors were normalized (mean subtracted and divided by the standard deviation) before constructing a dissimilarity matrix with them using Euclidean distances. PERMANOVA was used rather than MANOVA because the data failed to meet the assumptions of normality.

Results

Reproduction occurred in all months that populations of blackeye gobies were on the reefs, from July to March, with eggs clearly visible within saucer nests (Fig. 2B). Broods contained an average of 8664 (± 349) eggs, in an area of 43.8 (± 1.9) cm², with an average density of 215

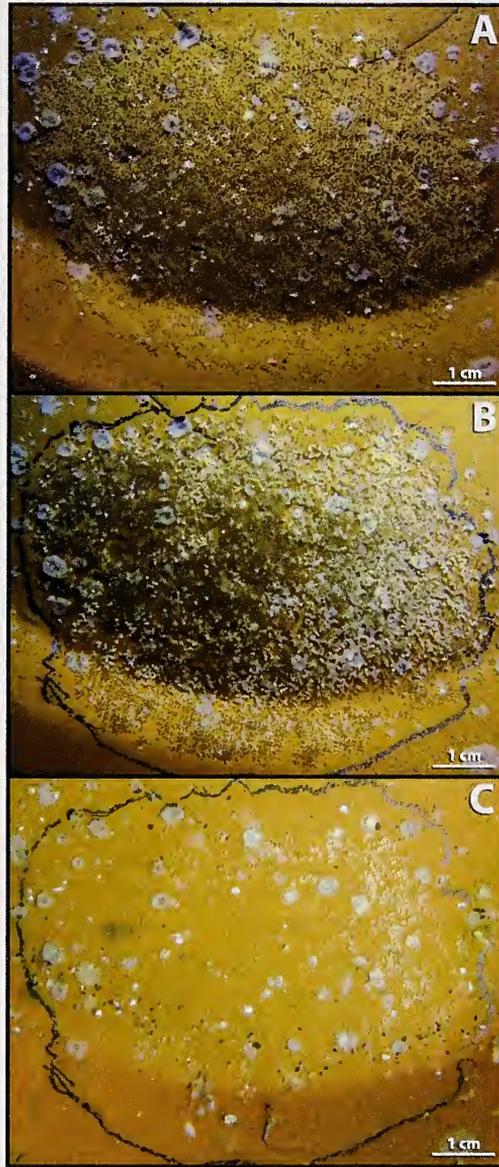


Fig. 3. Sequential weekly photographs of a single brood of eggs in a nesting saucer. A) Eggs in the recently laid brood appear pink/orange and the density of eggs is relatively uniform. B) Changes in color are seen within 7 days and close inspection reveals developed embryos inside eggs. C) After 14 days, all surviving larvae have emerged and the nest surface is bare.

(± 4) eggs cm^{-2} (mean \pm SE, $n = 240$). As described by Ebert and Turner (1962), recently laid eggs appeared pink/orange (Fig. 3A), transitioning to transparent as they developed (Fig. 3B). The eyes of developing embryos were visible in late-stage eggs, allowing differentiation of several clutches in a single nest. Identifiable individual clutches were observed in sequential photos taken a week apart on several occasions (Fig. 3), establishing a minimum incubation period of 7 days. Assuming eggs hatched within 24 hours after the second photograph of the

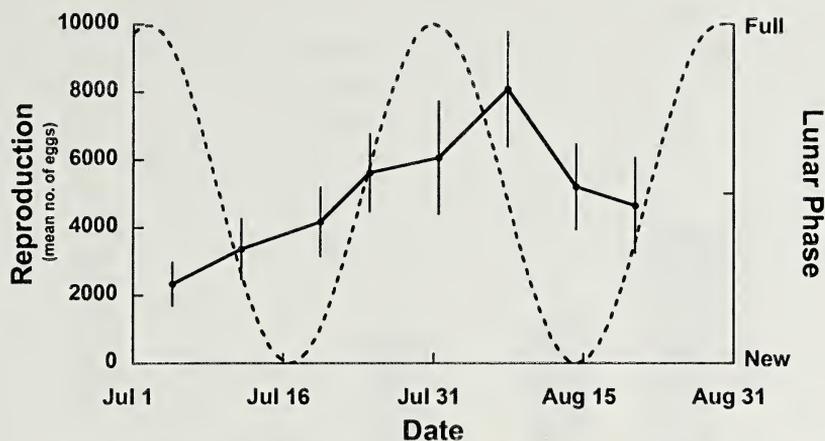


Fig. 4. The average number of eggs produced by reef populations (solid) relative to lunar phase (dashed) during two months in 2012. Cyclical patterns, coinciding with lunar phase or tidal amplitude were not apparent (see Results). Error bars represent ± 1 SE.

sequence, or 24 hours prior to the third photograph, then egg incubation time was between 8 and 13 days.

Blackeye gobies did not appear to time reproductive effort with any particular lunar phase, producing similar numbers of eggs during all four lunar phases (Pseudo- $F_{3,57} = 0.69$, $p = 0.56$, Fig. 4) and a similar number of nests during all four phases (27-33 nests). Moreover, reproductive output was unrelated to tidal amplitude, with similar numbers of eggs produced (mean \pm SE: 4461 ± 607 vs. 5461 ± 673 eggs; Pseudo- $F_{1,19} = 1.81$, $p = 0.18$) and similar numbers of active nests during spring and neap-tide periods (56 and 66), respectively.

Reproductive output was negatively correlated with water temperature (Spearman rank correlation: $r = -0.89$, $p = 0.02$), being higher on reefs in cooler portions of the study area than in warmer areas. This relationship appeared to be non-linear, with similar high reproductive output on reefs with average temperatures below 18°C , declining on reefs with average temperatures between 18 and 19°C (Fig. 5). Deeper reefs were colder on average than shallower reefs, as were reefs closer to the mouth of the cove compared to those in the middle or near the back (depth: $F_{1,336} = 19.77$, $p < 0.001$; position: $F_{2,336} = 13.77$, $p < 0.001$; depth \times position interaction: $F_{2,336} = 2.56$, $p < 0.08$; Fig. 6a). Reproductive output, however, did not differ statistically between depths or among positions (depth: $F_{1,14} = 2.34$, $p = 0.15$; position: $F_{2,14} = 0.08$, $p = 0.92$; depth \times position: $F_{2,14} = 0.35$, $p = 0.71$) due to high reef-to-reef variation (Fig. 6b).

The presence of a nest with eggs on a reef did not alter the multivariate behavioral response of fish living on that reef (Egg Presence \times Fish Class interaction: Pseudo- $F_{2,414} = 0.18$, $p = 0.99$; Egg Presence: Pseudo- $F_{1,414} = 1.06$, $p = 0.35$; Fig. 7). Despite the absence of a statistically significant difference in the multivariate behavioral response between times with eggs present vs. absent, males foraged 41% less when eggs were present (mean \pm SE: 0.55 ± 0.08 vs. 0.94 ± 0.18 bites per 5 min.; univariate PERMANOVA: Pseudo- $F_{1,138} = 5.24$, $p = 0.03$). Regardless of egg presence on a reef, behavioral rates differed among fish classes (Fish Class: Pseudo- $F_{2,414} = 65.34$, $p = 0.001$). Males were the most aggressive, females were intermediate, and juveniles were the least aggressive (Fig. 7). Feeding rates were the opposite, with juveniles feeding the most and males the least. Males courted and nested, whereas females and juveniles did not.

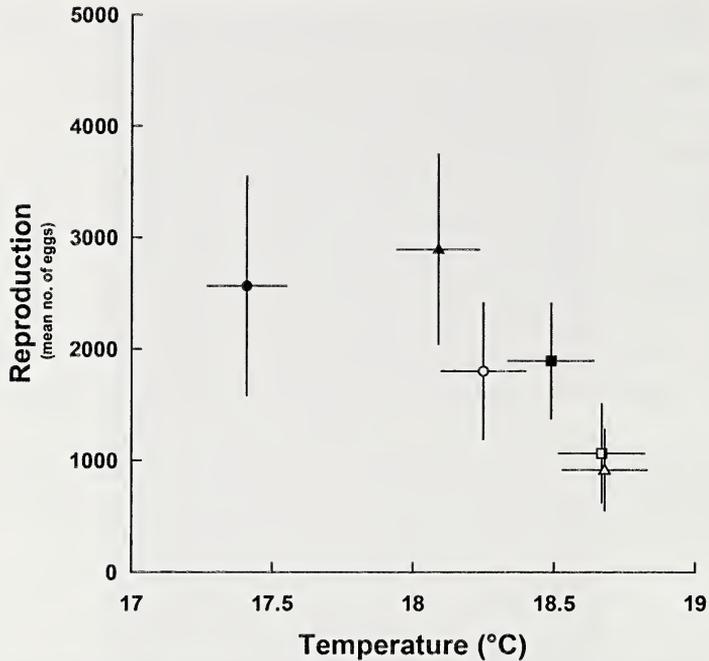


Fig. 5. Negative relationship between blackeye goby egg production and temperature. Reef Depth: closed = deep, open = shallow. Reef position: circle = far, triangle = middle, square = near. See Results for statistical details.

Discussion

Although reproductive lunar synchrony is thought to be prevalent in tropical habitats (Johannes 1978), it is relatively uncommon in temperate waters. Blackeye gobies appear to follow that trend, as they did not exhibit any noticeable lunar or tidal cycle in their reproductive activities. Thresher (1984) noted several hypotheses that would select for lunar reproductive patterns in marine organisms, two of which could explain the lack of lunar synchrony in blackeye gobies. One hypothesis is that reproduction is timed so that larvae hatch when food densities are high, which could have a lunar pattern. The other hypothesis is that lunar phase is a convenient way to synchronize reproductive efforts among numerous individuals (including those of multiple species), reducing larval mortality by swamping their predators. Johannes (1978) noted that temperate reef residents experience lower larval predation than tropical reef residents, which might result in lower selection for lunar synchrony of reproduction in temperate species like the blackeye goby. Similarly, a lack of lunar pattern in larval food abundance could explain a lack of lunar pattern in reproduction. Instead, continuous reproduction without lunar pattern might maximize lifetime fitness.

The absence of lunar synchrony might also be attributable to the long and variable larval duration of the blackeye goby. During their roughly two-month-long pelagic phase (Block 2011), larvae would experience several lunar cycles. Thus, timing reproductive effort to a particular lunar phase may result in negligible fitness gains. The large range of size at settlement in the blackeye goby (16 to 25 mm SL; Watson 1996), coupled with a variable pelagic duration, suggests variation or flexibility in larval growth rates and settlement potential. Larvae have been known to delay metamorphosis (McCormick 1999) despite having reached adequate settlement size (Victor 1986), presumably increasing exposure to potential settlement habitat. A similar

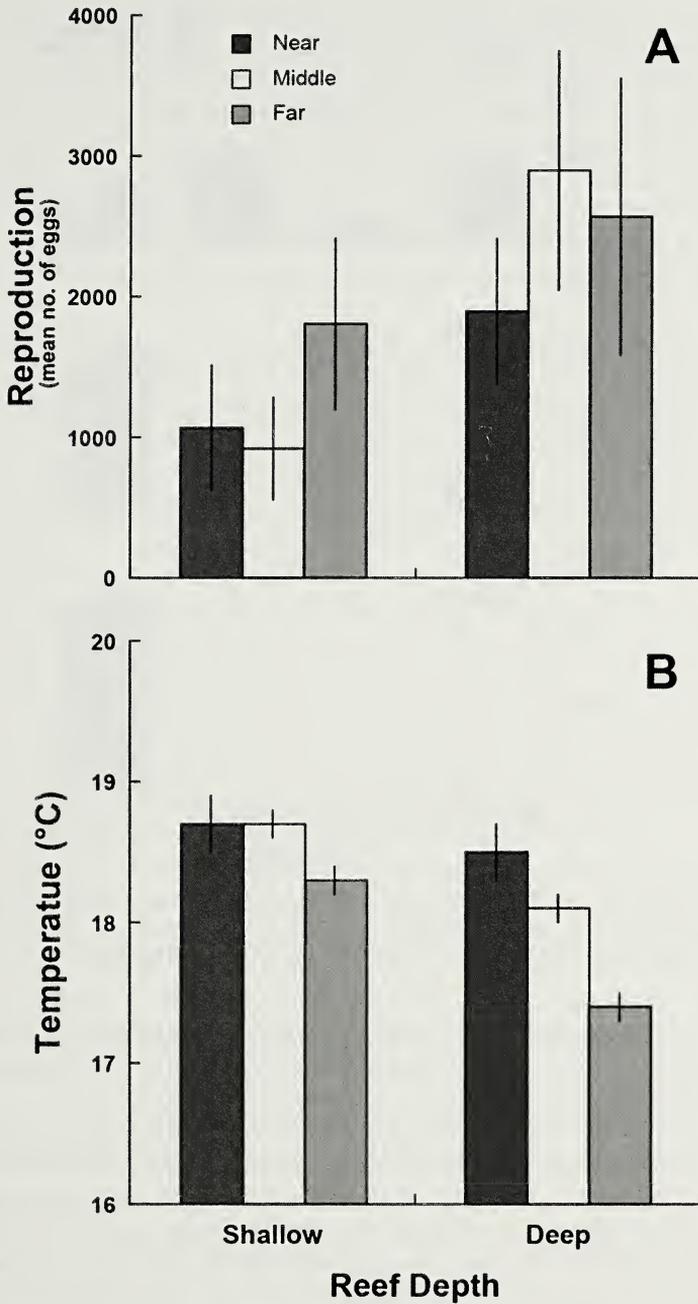


Fig. 6. A) Average egg production of blackeye gobies pooled over eight weeks for each reef depth and position combination during 2013. Differences in reproduction between depths or among positions were not statistically significant. ($n = 24$ or 32 for each group). B) Average temperature during the same eight weeks for each reef depth and position combination. Deep reefs and reefs farther from the back of the cove were colder than shallower reefs and reefs closer to the back of the cove ($n = 57$ days per bar). Error bars represent ± 1 SE (see Results for statistical details).

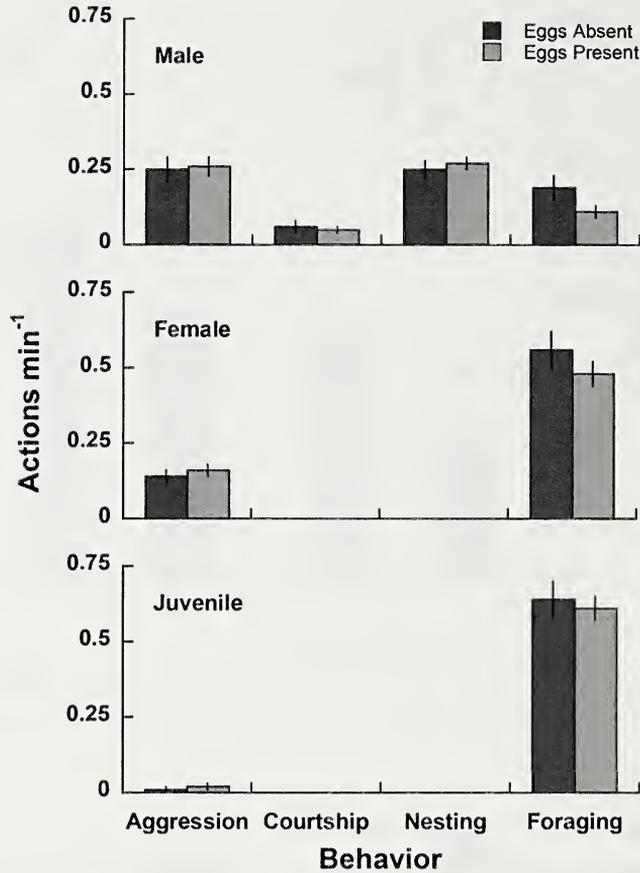


Fig. 7. Rates of behavioral expression when eggs were present in a nest on a reef or not, in the three classes of blackeye goby: male, female, and juvenile. The presence of eggs in a reef nest did not influence behaviors except male foraging (see Results). Means \pm 1 SE are shown ($n = 140$ observations per bar).

process may exist in blackeye gobies, promoting continuous reproduction, which supplies a pelagic larval stock that is capable of delayed and selective settlement, thus reducing risk of reproductive failure.

Temperature varied significantly within our array of reefs, and reproductive output reflected differences in temperature, decreasing with increasing temperature. Deeper reefs and reefs closer to the mouth of the cove were colder than shallower reefs and those nearer the back of the cove. These differences in temperature are due to the amount of time that those areas spent under the thermocline (MJS and MAS, *personal observations*). Differences in temperature are correlated with differences in nutrient concentrations (Dayton 1985; Dayton et al. 1998) and perhaps food availability (e.g., zooplankton). Therefore, differences in reproduction related to water temperature might not be driven by temperature differences per se. Nevertheless, temperature and day length are generally recognized as the two of the most widespread environmental cues for seasonal reproduction, and within the reproductive season, there may be thermal optima (Shrode and Gerking 1977; Gerking et al. 1979). The wide geographic range (British Columbia to Baja California) and depth range (intertidal to 80 m; Love 2011) occupied by the blackeye goby indicates that it is adapted to a wide range of temperatures, but reproduction may be reduced at warmer times or places.

We documented blackeye goby reproduction during each month from July through late March. When coupled with Ebert and Turner's (1962) account of nesting from April through October, there is documented evidence for year-round reproduction by the blackeye goby in southern California, supporting claims of year-round reproduction by Love (2011). Breitburg (1987) observed reproduction only between March and October at her study site near Santa Barbara, California. It is possible that reproduction occurs year-round in warmer locations but only seasonally in cooler areas. Temperature is known to affect both incubation time (Lasker 1964; Miranda et al. 1990) and larval growth rates (O'Connor et al. 2007) which may help explain the seasonality observed in populations experiencing cooler average annual temperature.

Our estimates of brood size were more than five times greater than the 1700 eggs in a single nest reported by Ebert and Turner (1962). Based on Wiley's (1973) estimation of female fecundity ranging from 3274 to 4788 eggs ($n = 4$ females), a minimum of two females would be necessary to account for the 8663 eggs per nest recorded in this study; however, female sizes were not included with Wiley's estimates. Since female fecundity is known to increase exponentially with body length (Duarte and Alcaraz 1989) it is possible that a single large female could produce the average number of eggs observed here. Conversely, the large number of eggs per nest found in the present study could be the product of multiple females spawning in a single nest over a short period of time. If female blackeye gobies exhibit similar nesting preferences and habits as a number of damselfishes that have been studied, multiple females may lay eggs in a single nest over a short period, producing what appears to be a single large clutch (Sikkel 1989; Knapp et al. 1995). Love (2011) stated that males may defend the clutches of up to 6 females; however, one or two females appears to be typical, which is in line with a reported population sex ratio of 1.7 females per male (Wiley 1973). Although more than one clutch in a single nest was observed on several occasions (based on the presence of non-contiguous clutches and eggs of different stages), the majority of nests appeared to contain a single clutch.

The exact incubation period for blackeye goby eggs could not be determined from our once-a-week photos, but it must have been more than 7 days and less than 14. While increasing the frequency of nest observations could provide a more accurate estimate of incubation time, the consistent disruption necessary might also result in nest abandonment or filial cannibalism by guarding males, biasing estimates low. An attempt was made to passively observe reproduction in clear acrylic aquaria equipped with flow through seawater, but no eggs were produced in either of two lab populations over a month. Aquaria were set up similar to the small reefs used in the field (i.e., rock rubble collected under water and artificial nesting saucers), but sand was not included, as it would have obscured the view of the nest.

Behaviors of males, females, and juveniles were mostly unaltered by the presence of eggs on the reef. Surprisingly, rates of aggression and nesting behavior by males did not change despite guarding a nest containing eggs. Foraging rates of males guarding eggs were, however, about 40% lower than when eggs were absent. While eggs were present in the nest, males continued to court females, despite the potential for damaging or dislodging eggs already in the nest. The costs and benefits of the behaviors we quantified may depend on context, however. For example, work on other fishes has shown that territorial defense can be affected by population density (Warner and Hoffman 1980); and male foraging rates can be influenced by male territorial strategies (Hoffman 1983). Although we stocked our artificial reefs with densities reflecting those on natural reefs at Catalina at the time (~ 6 individuals m^{-2} , MJS pers. obs.), higher densities are sometimes observed in nature, e.g., up to 20 individuals m^{-2} (Love 2011; Steele, unpublished data). Behavioral responses to the presence of nests with eggs might differ in those higher-density populations. More artificial nest sites were present on our reefs than were used,

indicating this resource was not limited, which could alleviate density-dependent competition for preferred nesting space.

Results from this study indicate that blackeye gobies reproduce year-round, and without any lunar or tidal patterns. These findings suggest this species maximizes reproduction over a protracted period and it employs a bet-hedging strategy by spreading out reproductive efforts, thereby reducing the risk of reproductive failure. Whether this reproductive strategy is employed by the blackeye goby throughout its very broad geographic range is an interesting question that is amenable to study because reproductive output in this species is relatively easy to measure using the methods described in this paper.

Acknowledgements

We thank S. Ranson, C. Paterson, and N. Gan for field assistance. We appreciate the logistical support provided by the staff of the University of Southern California Wrigley Marine Science Center field station. Drs. M. Adreani and L. Allen provided useful advice, and they and three anonymous reviewers provided helpful comments on drafts of this manuscript. This research was supported by funding from the CSU Northridge Association of Retired Faculty, CSUN Graduate Thesis Support, the CSUN Peter Bellinger student research award, CSU-COAST, Sigma Xi, the USC Rose Hills Foundation Summer Fellowship, and the National Science Foundation (OCE-1437571). This is contribution # 252 from the Wrigley Marine Science Center.

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The Largemouth Blenny, *Labrisomus xanti*, New to the California Marine Fauna with a List of and Key to the Species of Labrisomidae, Clinidae, and Chaenopsidae found in California Waters

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We report here on the first observations and capture of breeding populations of the largemouth blenny, *Labrisomus xanti* Gill, 1860 (Family Labrisomidae) in California marine waters. We also provide a list of those members of the closely related families Labrisomidae, Clinidae, and Chaenopsidae that are found off California with a key to these species.

The first observation of this species in California waters occurred on 15 July 2015, when Callie Mack and Tara Howell observed one individual in about 5 m of water in front of the Marine Room Restaurant (La Jolla Shores) (32°51'N, 117°16'W) among low lying rocks. Ms. Mack described the fish as having “a blenny-like profile, about 6 or 7 inches long (the length of my hand), bright red and covered with many small blue spots, and a partial bright blue ring at the base of each eye. It was perched in a rock crevice on its red pelvic fins. Pectoral fins were red shading to yellow. Dorsal fin was also bright red with blue spots on the foredorsal [sic] part. It had 3 rows of small fur-like (or eyelash-like) cirri, also covered with blue spots, on the top of its head, one set just below each eye, and 2 rows above the eyes on the forehead. It was either curious or territorial (probably the latter); kept coming out of its crevice, sitting in the open for a few moments, then going back in.”

Ms. Mack and Ms. Howell returned to the same general area on 19 July 2015 and observed at least four different individuals, two on each dive and all at a bottom depth of 3–4 m. On this occasion she provided us with a number of images of one of the individuals that was red and she described it as quite territorial as it chased off a California sheephead and lunged at Ms. Howell’s video camera. From Ms. Mack’s initial description, and her subsequent photographs, we determined that these fish were most likely the largemouth blenny, *Labrisomus xanti* and that the red individuals were breeding males (Thomson et al. 2000).

Additional observations were made of this species at the same general site on 11 and 19 August 2015 by Roger Uzun who observed at least five unique individuals. Similar to previous sightings, he observed the fish at depth of 3–4 m on low-lying rocks. However on these days, Mr. Uzun observed what was likely mating behavior and nest guarding. On both 11 and 19 August, he observed, photographed, and video recorded a bright red individual (Fig. 1) courting and apparently fertilizing the eggs of two drabber individuals (Fig. 2). This male then guarded and aerated the apparent eggs. Similar courtship and parental behaviors are known for other species of the genus *Labrisomus* (Gibran et al. 2004).

Janna Nichols made the first observation of this species known to us away from the La Jolla area on 31 October 2015 off Casino Point at Santa Catalina Island (33°20.9'N, 118°19.4'W) in

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Fig. 1. Male largemouth blenny, *Labrisomus xanti*, photographed near La Jolla, California, August 2015. Photograph by Roger Uzun.

about 7 m of water among rocks. Based on the images Ms. Nichols provided, the Casino Point fish (brownish-gray) may have been a female or a male (mature males lose their red coloration during the non-reproductive season — Mark Steele, pers. comm. to M. L.). Ms. Nichols notes that she likely saw another, similarly colored, individual later in the day off Torqua Springs (33°23.0'N, 118°21.6'W) about 5 km up northwest of Casino Point.

Through December, recreational divers continued to see at least several individuals on the shallow Marine Room reefs. However, we received no reports of *L. xanti* sightings from unique areas until Dan Richards and party found several fish, again at Catalina Island, but this time further west of the previous sightings. Mr. Richards, along with Steve Lee and Jessie Altstatt, saw one individual among cobbles in 5–6 m in Big Fisherman Cove (33°26.7'N, 118°29.1'W) on 2 May 2016. On 4 May 2016, Mr. Richards saw an additional fish under a small rocky overhang in 3 m of water at nearby Isthmus Reef.

Lastly, Mark Steele informs us that, as of late summer and early fall 2016, “I searched a band that was approximately 150 m long and 3 m wide in 1.2–2 m depth in the back of Big Fisherman Cove and counted 19 different individuals. This was not an exhaustive search and this species is pretty shy, so I’m sure 19 is an underestimate of true abundance in that area.” He goes on to note that an associate had also seen this species at several other sites around the island.



Fig. 2. Female (left) and male (right) largemouth blennies, *Labrisomus xanti*, exhibiting breeding behavior, August 2015, La Jolla, California. Photograph by Roger Uzun.

Table 1. Members of the families Clinidae, Labrisomidae, and Chaenopsidae from California waters with notes on their maximum sizes, and geographic and depth ranges. CAS = California Academy of Sciences; LACM = Los Angeles County Museum of Natural History; SIO = Scripps Institution of Oceanography Marine Vertebrate Collection. Min. = minimum depth observed; max. = maximum depth observed. D = dorsal-fin elements; A = anal-fin elements; Pect. = pectoral-fin rays; Pelvic = pelvic-fin rays; Ls = lateral line scales; LLp = pored lateral line scales; GR = gill rakers, lower + upper; GRt = total gill rakers; Vert. = total vertebrae.

Family Clinidae — Kelp Blennies

Gibbonsia elegans (Cooper, 1864). Spotted Kelpfish. To 16 cm TL (Miller et al. 2008). San Francisco Bay (CAS 215456), northern California to Bahia Magdalena, southern Baja California, including Isla Guadalupe (Eschmeyer and Herald 1983). Intertidal and to 56 m (min.: Wells 1986; max.: Eschmeyer and Herald 1983). D XXXI–XXXV,5–8; A I–III,21–25; Pect. 11–13; Pelvic I,2–3; LLp 62–71; GR 4–5 + 8–12 = 12–16; Vert. 47–49. The spotted kelpfish was mistakenly given the name *Gibbonsia evides* by Eschmeyer (1998); for explanation see Nelson et al. (2004:243).

Gibbonsia metzi Hubbs, 1927. Striped Kelpfish. To 23.5 cm TL (Miller and Lea 1972). Vancouver Island, British Columbia to Punta Rompiente, central Baja California (Miller and Lea 1972). Intertidal, including tide pools, and to 18 m (min.: Eschmeyer and Herald 1983; max.: LACM 35689-2). D XXXIV–XXXVII,7–10; A II,24–29; Pect. 11–13; Pelvic I,3; LLp 64–71; GR 3–4 + 7–8 = 11; Vert. 50–53.

Gibbonsia montereyensis Hubbs, 1927. Crevice Kelpfish. To 13.9 cm SL (SIO 80–19). Vancouver Island, British Columbia (Lamb and Edgell 2010) to Isla Guadalupe (SIO 60–15), Bahia San Carlos (SIO 52–215) and Isla Cedros, Islas San Benito, and Isla Natividad, central Baja California (Ramírez-Valdez et al. 2015). Intertidal and to 37 m (min.: M. L., unpubl. data; max.: J. Carroll, pers. comm. to M. L.).

Gibbonsia erythra Hubbs, 1952, is a junior synonym (Stepien and Rosenblatt 1991). D XXXIV–XXXVI,5–8; A II, 23–28; Pect. 11–13; Pelvic I,3; LLp 61–70; GR 2–5 + 7–10; Vert. 49–51.

Heterostichus rostratus Girard, 1854. Giant Kelpfish. To 61 cm TL (Miller and Lea 1972). British Columbia to Cabo San Lucas, southern Baja California, including Isla Guadalupe (Miller and Lea 1972). Intertidal and to 40 m (min.: M. L. unpubl. data; max.: Eschmeyer and Herald, 1983). D XXXIII–XXXVIII,11–13; A II,31–35; Pect. 12–14; Pelvic I,3; Ls 73–83; GR 5–8 + 12–13 = 18–20; Vert. 56–58.

Family Labrisomidae — Labrisomid Blennies

Alloclinus holderi (Lauderbach 1907). Island Kelpfish. To 11.5 cm TL (M. L., unpubl. data). San Miguel Island, southern California (D. Kushner, pers. comm. to M. L.) to Punta San Pablo (27°12'N, 114°29'W), southern Baja California (Miller and Lea 1972). Intertidal and to 91 m (min.: M. L., unpubl. data; max.: SCCWRP). D XXIV–XXVI,9–13; A II,21–23; Pect. 13–14; Pelvic I,3; Ls 47–54; GR 4 + 9; Vert. 41–42.

Cryptotrema corallinum Gilbert, 1890. Deepwater Blenny. To 12.7 cm TL (Miller and Lea 1972). Off Cook Point, San Miguel Island, southern California (D. Schroeder, pers. comm. to M. L.) to Bahia San Quintin, northern Baja California (Miller and Lea 1972). At depths of 24–195 m (min.: Miller and Lea 1972; max.: M. L., unpubl. data). D XXVI–XXVIII,11–13; A I–II,24–27; Pect. 13–15; Pelvic I,3; Ls 65–75; GR 4–5 + 8–12.

Labrisomus xanti Gill, 1860. Largemouth Blenny. To 17.8 cm TL (Thomson et al. 2000). Agua Hedionda Lagoon, La Jolla, and Santa Catalina Island, southern California (C. Mack, B. Cantrell, and J. Nichols, respectively, pers. comm. to M. L.); Isla Cedros and Isla Natividad (Ramírez-Valdez et al. 2015) and (mainland) Bahia de Sebastian Vizcaino, southern Baja California into Gulf of California (Thomson et al. 2000) and to Bahia Chamela, Jalisco, Mexico (Galván et al. 2016). Tide pools and to 11 m (min.: Thomson and Lehner 1976; max.: LACM 31768.028. D XVII–XIX,10–13; A II,17–19; Pect. 13–15; Ls 64–69; GR 3 + 6–7; Vert. 34.

Paraclinus integripinnis (Smith, 1880). Reef Finspot. To 7.8 cm TL (Rosales-Casián 1996). Santa Cruz Island, southern California (Rosenblatt and Parr 1969) and Naples, Santa Barbara County, southern California (S. Norton, pers. comm. to M. L.) to Bahia Almejas, southern Baja California (Miller and Lea 1972). Intertidal and to 15 m (Miller and Lea 1972). D XXVII–XXIII; A II,18–21; Pect. 12–14; Pelvic O–I,3; Ls 34–39; GR 2 + 4 = 6; Vert. 37–39.

Family Chaenopsidae — Tube Blennies

Chaenopsis alepidota (Gilbert, 1890). Orangethroat Pikeblenny. To 15.2 cm TL (Miller and Lea 1972). Point Sur, central California (T. Laidig, pers. comm. to M. L.) to Gulf of California (Thomson et al. 2000). The only known mainland population in southern California is in King Harbor, southern California (Stephens et al. 1989). At depths of 1–23 m (min.: Robertson and Allen 2002; max.: Allen and Robertson 1994). D XVIII–XXI,32–38; A II,34–38; Pect. 12–14; Pelvic I,3; GRt 11–12; Vert. 56–60.

Table 1. Continued.

<i>Neoclinus blanchardi</i> Girard, 1858. Sarcastic Fringehead. To 30.5 cm TL (Miller and Lea 1972). Bodega Bay, northern California (D. Stephens, pers. comm. to M. L.) to Isla Cedros, central Baja California (Miller and Lea 1972). At depths of 3–73 m (min.: Miller and Lea 1972; max.: Carlisle 1969). D XXIII–XXVII, 15–18; A II, 26–30; Pect. 14–15; Pelvic I, 3; LLs 20–27; GR 4–6 + 8 = 12–14; Vert. 46–49.
<i>Neoclinus stephensae</i> Hubbs, 1953. Yellowfin Fringehead. To 10 cm TL (Miller and Lea 1972). San Francisco, northern California (Ryan 1986) to Punta San Hipolito, central Baja California (Miller and Lea 1972). Intertidal (Hubbs 1953) to 27 m (Miller and Lea 1972). D XIV–XXVII, 15–18; A II, 29–31; Pect. 15; Pelvic I, 3; LLs 19–20; GR 6–8 + 12–14 = 18–22; Vert. 47–50.
<i>Neoclinus uninotatus</i> Hubbs, 1953. Onespot Fringehead. To 25 cm TL (Eschmeyer and Herald 1983). Bodega Bay, northern California to northern Baja California (Eschmeyer and Herald 1983). Surf zone to 55 m (min.: Carlisle et al. 1960; max.: Fay et al. 1978). D XXIII–XXVII, 14–17; A II, 26–31; Pect. 14–16; LLs 17–26; GR 3–5 + 8–11 = 11–16; Vert. 47–49.

Through all of these sightings we were fairly confident in our identification of this species as *L. xanti*, based on overall appearance and coloration of the breeding males. However, we felt that publishing this report had to await our being able to examine a specimen. This opportunity was provided by the third author (BC) who caught three individuals, using hook-and-line, on 30 June 2016 in Agua Hedionda Lagoon (33°08.8'N, 117°19.9'W). He caught these specimens in an area of the lagoon that is lined by small boulders that occur from above the tide line into the shallow subtidal. He reports that of the first three fish he caught one was a male and two were females. Returning on 6 July 2016, he caught five more at low tide. Good water clarity allowed him to see other *L. xanti* under a number of barely subtidal boulders.

These five specimens were deposited in the Scripps Institution of Oceanography Marine Vertebrate Collection (SIO 16-30) and range in size from 97.2 to 122.3 mm SL. All specimens fit the description of *L. xanti* (Hubbs, 1953), having relatively few cephalic sensory pores (compared to the similar species *L. multiporosus*), no teeth on the palatine, XVIII–XIX dorsal-fin spines, 12–13 dorsal-fin rays, two anal-fin spines and 16–18 rays. The largest specimen is a ripe male that was bright red with iridescent blue spots when captured. Three specimens are females with ripe eggs, confirming the presence of spawning-capable individuals in southern California waters.

Prior to this the known distribution of the Largemouth Blenny included the Pacific coast of Mexico, from the outer Baja peninsula, the Gulf of California, and southward to southern Mexico (Hubbs 1953; Springer 1959; Thomson et al. 2000). It is known from throughout the Gulf of California from Roca Consag (SIO 04-124; 31°7.3'N, 114°29.0'W) southward to Mazatlán and is the most common species in the genus found in the Gulf (Thomson et al. 2000). It is found along the Pacific coast of southern Mexico with confirmed records as far south as Bahía Chamela, Jalisco (Galván-Villa et al. 2016). It has also been recorded from the Islas Tres Marias (Erismán et al. 2015) including Isla San Juanito (SIO 62-8, 62-9; 21°43.5'N, 106°42.3'W) and Isla Cleopha (SIO 62-56; 21°15.5'N, 106°17.6'W), as well as Isla Clarion (LACM 32097-47; 18°21'N, 114°43'W). Reports of the species from Peru (e.g., Love et al. 2005) and Ecuador (Bearez 1996) appear to be based on its inclusion in keys to fish species of that region (Chirichigno 1974; Chirichigno and Vélez 1998). It was listed as occurring in northern Chile in 1999 (Sielfeld et al. 2010) but that record may be based on the similar species *L. multiporosus*, known to occur in that area (Hubbs 1953; Springer 1959). *Labrisomus xanti* was not recorded in a detailed systematic treatment of related blennies from the Pacific coast of South America (Stephens and Springer 1974), and to our knowledge no specimens from south of Mexico exist. Thus its occurrence south of Mexico is unconfirmed.

Along the outer coast of Baja California *L. xanti* had been recorded as far north as Puerto Mala Arrimo in Bahía San Sebastián Vizcaíno (SIO 14-174, formerly W51-224; 27°48'N, 114°43'W). Hubbs (1953) reported the species (as *Labrisomus xanthusi*) from Isla San Benito based on two specimens collected in 1950 (SU 17545; ca 28°18'N, 115°35'W). The species has also been reported from Rocas Alijos (ca 24°57.5'N, 115°45'W) based on visual observations (Gotshall 1996). The southern California records represent the northernmost occurrence of the species, extending its known range approximately 626 km northward from Isla San Benito to Santa Catalina Island, California.

These records are the first from California. Whether the species arrived in these waters as larvae, juveniles, or as adults (unlikely given their benthic habits), is unknown. We note that the first individuals observed were adults. It is one of the numerous tropical fishes that arrived in California waters during the strong El Niño of 2015. While we have documented that the fish were breeding off La Jolla in 2015 and Agua Hedionda in 2016 it remains to be seen whether recruitment from these spawning sites will be successful. We note that as of fall 2016, no young or newly recruited individuals have been observed. Thus, it is possible that successful reproduction will not occur and that this species will disappear over time from California waters.

Key to the California Kelp, Labrisomid, and Tube Blennies, Families Clinidae, Labrisomidae, and Chaenopsidae

- 1a Large ocellus present in posterior portion of dorsal fin (between 22nd to 27th dorsal-fin spines); dorsal fin wholly of spines *Paraclinus integripinnis* (Labrisomidae)
- 1b No ocellus in dorsal fin as above; dorsal fin with both spines and soft-rays 2
- 2a Greatest body depth into total length more than 10 times; more soft-rays than spines in dorsal fin *Chaenopsis alepidota* (Chaenopsidae)
- 2b Greatest body depth into total length less than 8 times; more spines than soft-rays in dorsal fin 3
- 3a Maxillary extending well behind eye 4
- 3b Maxillary not extending behind eye 6
- 4a Supraorbital cirri divided from base; no large ocellus in center of membrane between 1st and 2nd dorsal spines; total gill rakers 18–22; head length 4.2–5.3 into standard length *Neoclinus stephensae* (Chaenopsidae)
- 4b Supraorbital cirri simple or divided only on distal half; ocellus present between 1st and 2nd dorsal-fin spines; total gill rakers 11–16; head length 3.5–3.8 into standard length. . . 5
- 5a One ocellus in dorsal fin between 1st and 2nd spines, none between 5th to 9th spines; anteriormost supraorbital cirrus longer than eye and divided at tip *Neoclinus uninotatus* (Chaenopsidae)
- 5b Two ocelli in dorsal fin (rarely one; if one, located between 1st and 2nd dorsal spines), one between 1st and 2nd spines, the other between 5th to 9th spines; all supraorbital cirri shorter than eye and undivided *Neoclinus blanchardi* (Chaenopsidae)
- 6a From 3b: maxillary not extending behind eye
Tail forked; head elongated and pointed; anal-fin soft-rays 30 or more *Heterostichus rostratus* (Clinidae)
- 6b Tail rounded (in adults); head not as above, more stout; anal-fin soft-rays less than 30. . . 7
- 7a Pectoral fin long, extending beyond 1st anal-fin soft-ray; maxillary goes into head less than 2.5 times 8

- 7b Pectoral fin short, not extending to 1st anal-fin soft-ray; maxillary goes into head more than 2.5 times 10
- 8a Ocellus between 2nd and 3rd dorsal-fin spines typically present; supraorbital cirri heavily branched; anal-fin soft-rays 17 to 19 *Labrisomus xanti* (Labrisomidae)
- 8b No ocellus on dorsal fin (Island Kelpfish may have dark patch on 1st and 2nd dorsal spine); supraorbital cirri simple, with 2 or more tips; anal-fin soft-rays 21 or more 9
- 9a Lateral line descends to midbody immediately posterior to tip of pectoral fin; anal-fin soft-rays 21–23 *Alloclinus holderi* (Labrisomidae)
- 9b Lateral line remains in upper portion of body for at least 2/3 of distance to caudal fin; anal-fin soft-rays 24–27 *Cryptotrema corallinum* (Labrisomidae)
- 10a Dorsal-fin soft-rays equally spaced, 7–10 in number; total length may be >16 cm *Gibbonsia metzi* (Clinidae)
- 10b Dorsal-fin soft-rays not equally spaced, posterior spacing wider than anterior, 5–8 in number; total length <16 cm 11
- 11a Scales present on caudal fin; ocellus on body with ring *Gibbonsia elegans* (Clinidae)
- 11b No scales on caudal fin; ocellus on body with no ring *Gibbonsia montereyensis* (Clinidae)

Acknowledgments

We thank Callie Mack, Tara Howell, and Roger Uzun for bringing this species to our attention and to John Moore, Wendy Dorr, Bill Bushing, Janna Nichols, Dan Richards, and Mark Steele for further observations. We thank John Snow for helping us obtain the specimens, and Rick Feeney for confirming identifications of museum specimens. The following researchers reviewed the key: Don Buth, Craig Campbell, Dario Diehl, Rick Feeney, Robin Gartman, Peter Major, Jim Mann, Mike Mengel, Terra Petry, Bill Power, Jim Rounds, and Fred Stern.

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Records of Wahoo, *Acanthocybium solandri* (Scombridae), from California

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The summers of 2014 and 2015 generated many tales of warm-water fishes being caught in the local southern California sport fishery, including Dolphinfin (*Coryphaena hippurus*), Blue Marlin (*Makaira nigricans*), Shortbill Spearfish (*Tetrapturus angustirostris*), Yellowfin Tuna (*Thunnus albacares*), and Wahoo (*Acanthocybium solandri*) among other tropical species. The news media (both print and television), sport fishing reports, and photographic records of Wahoo caught off California were numerous. For example, Phil Friedman (PFORadio.com) reported Wahoo being caught at 14-Mile Bank, off Orange County (33°23.92'N, 118°00.20'W) on October 4, 2015. Alex Dobuzinskis (Reuters, November 13, 2015) reported that in 2015 there were 256 catches of Wahoo by party boats from Southern California according to Chad Woods of the Sportfishingreport.com. Currently, Kells, Rocha, and Allen (2016) list the range as “recently recorded from Newport Beach and San Diego, CA. Historically south of the U.S.-Mexican border to Peru, including southern Gulf of California and Galápagos Islands.”

There have been unsubstantiated reports from previous years. Pete Thomas writes of a Wahoo being snagged in Alamitos Bay in 2010¹, but, it may have been transported there by long-range fishing vessel and released. In the period of 1997-99 while compiling records of tropical fishes occurring off California during the 1997-1998 El Niño event, Lea and Rosenblatt (2000) received several reports of Wahoo being caught off southern California. However, without photo documentation or a substantiating specimen, these reports were not included. A search of all the museum online databases revealed no preserved museum specimens from north of the United States – Mexico boundary. There is one LACM specimen (37950-1) from the San Pedro Fish Market, California, recorded in 1966 (a year of normal sea surface temperature) but with no specific locality data. This specimen could have reached the market from anywhere in the eastern tropical Pacific. To date, there have been no museum specimens preserved from California waters, this being the first.

The first Wahoo documented from California was caught on August 30, 2014 and weighed in at the Balboa Angling Club in Newport Beach (Western Outdoor News, Sept. 5, 2014). The fish was caught by Eric Kim about 32 km (20 mi.) off Newport near the 267 spot (approx. 33°18'N, 117°50'W). It measured 152.4 cm (60 in.) in length and weighed 22.7 kg (50.1 lbs.). Following this catch there were at least eight additional Wahoo landed in September. These came from three areas: off San Diego (9 Mile Bank and Hidden Bank), San Clemente Island, and the waters outside Dana Point. Weights for these fish were from 15.9 to 21.5 kg (35 to 47.3 lbs.). In late October, a 38.2 kg (84.3 lbs.) fish was caught out of Dana Point Harbor; the water was 22.7° C (72.8° F)². In October there were several reports of Wahoo, in the 18-22 kg (40-48 lbs.) range that were landed by spear fishermen³.

¹ <http://www.petethomasoutdoors.com/2010/09/believe-it-or-not-angler-catches-a-wahoo-in-alamitos-bay.html>

² <http://www.sportfishingmag.com/news/angler-lands-biggest-wahoo-ever-southern-california-waters>

³ <https://www.youtube.com/watch?v=BUGnwL4r2sI>



Fig. 1. *Acanthocybium solandri* collected near Oceanside, California, 2015 (LACM 58300-1, head)

In 2015 the first Wahoo from California was caught on 29 August 2015 and weighed in at the Balboa Angling Club (Western Outdoor News, Sept. 4, 2015). The fish was reported as being caught by Mikko Monte at the 17-Fathom Spot (17°43.70'N, 119°09.60'W) and measured 151.7 cm (59.75 in.) and weighed 23.8 kg (52.58 lbs.). In October, a Wahoo was caught in Santa Monica Bay, off Redondo Beach, which would establish that latitude as the most northern record to date (Western Outdoor News, October 23, 2015). In mid-December 2015, a Wahoo was caught on hook and line by Shawn Aulby near Oceanside, off Box Canyon (33°10.986'N, 117°26.261'W) in 91 m (300 ft.) of water. The head and tail were brought to the Natural History Museum by Phil Friedman where they were photographed and cataloged as the first California museum specimen, (LACM 58300-1, Fig. 1). Tissue was taken (T-001257) and stored in the Ichthyology ultracold freezer.

Of the family Scombridae, Wahoo is perhaps one of the most distinctive members of this group, exhibiting a number of unique characters (Collette and Nauen 1983). This species is an elongate scombrid and the posterior end of the maxilla is concealed under the pre-orbital bone. It has a relatively long snout, the snout being about as long as the rest of the head. In this specimen, the snout (139 mm) is slightly shorter than the rest of the head (143 mm) or 49.3% of head length. All of the other scombrid genera known to occur off California have snout lengths

Table 1. Head measurements and ratios of selected scombrid taxa known from California. (FL = fork length, HL = head length, SL = snout length, HD = head depth at middle of eye. *T. albacares* is assumed to be representative of the other species within the genus. Fitch and Craig are measurements from Fitch and Craig (1964).

Taxon	Catalog	FL	HL	HL/FL	SL	SL/HL	HD	HD/SL
<i>Acanthocybium solandri</i>	58300-1		282		139	0.49	100	0.72
<i>Allothunnus fallai</i>	Fitch & Craig	722	187	25.90	55	0.29		
<i>Auxis rochei</i>	6707-1	376	93	24.73	21	0.23	40	1.90
<i>Auxis thazard</i>	6711-8	378	103	27.25	21.5	0.21	42	1.95
<i>Euthynnus affinis</i>	6711-12	200	58.5	29.25	16	0.27	27	1.69
<i>Euthynnus lineatus</i>	52024-14	385	115	29.87	30	0.26	62	2.07
<i>Katsuwonus pelamis</i>	48925-1	488	138	28.28	40	0.29	60	1.50
<i>Sarda chiliensis</i>	32031-1	410	109	26.59	37	0.34	47	1.27
<i>Scomber japonicus</i>	44756-4	209	55.5	26.56	18.5	0.33	23.5	1.27
<i>Scomberomorus concolor</i>	22582	550	114	20.73	37	0.32	45	1.22
<i>S. sierra</i>	32085-27	451	98	21.73	36	0.37	42.5	1.18
<i>Thunnus albacares</i>	48300-1	495	147	29.70	43	0.29	82	1.91

about 21-37% of head length (Table 1). Additionally, the ratio of the head height at the middle of the pupil to the snout length ($100/139 = 0.72$) is low compared to other California scombrids (1.18-2.07) (Table 1).

According to NOAA the El Niño conditions off California have persisted throughout 2015, even into 2016, bringing anomalously warm water to northern latitudes (NOAA, Climate Prediction Center/NCEP, 2016⁴). The addition of Wahoo to the California ichthyofauna brings the number of species of scombrid fishes to 15. The Wahoo has a designation of “Least Concern” on the IUCN Red List of Threatened Species (Collette et al. 2011).

Acknowledgements

We thank Shawn Aulby and Phil Friedman for catching and bringing in a specimen for us. We thank Bruce Collette for providing comments on the manuscript. We also thank Camm Swift for information on several catches.

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⁴ http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf





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