

Sea-level rise and refuge habitats for tidal marsh species: Can artificial islands save the California Ridgway's rail?



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ABSTRACT

Terrestrial species living in intertidal habitats experience refuge limitation during periods of tidal inundation, which may be exacerbated by seasonal variation in vegetation structure, tidal cycles, and land-use change. Sea-level rise projections indicate the severity of refuge limitation may increase. Artificial habitats that provide escape cover during tidal inundation have been proposed as a temporary solution to alleviate these limitations. We tested for evidence of refuge habitat limitation in a population of endangered California Ridgway's rail (*Rallus obsoletus obsoletus*; hereafter California rail) through use of artificial floating island habitats provided during two winters. Previous studies demonstrated that California rail mortality was especially high during the winter and periods of increased tidal inundation, suggesting that tidal refuge habitat is critical to survival. In our study, California rail regularly used artificial islands during higher tides and daylight hours. When tide levels inundated the marsh plain, use of artificial islands was at least 300 times more frequent than would be expected if California rails used artificial habitats proportional to their availability (0.016%). Probability of use varied among islands, and low levels of use were observed at night. These patterns may result from anti-predator behaviors and heterogeneity in either rail density or availability of natural refuges. Endemic saltmarsh species are increasingly at risk from habitat change resulting from sea-level rise and development of adjacent uplands. Escape cover during tidal inundation may need to be supplemented if species are to survive. Artificial habitats may provide effective short-term mitigation for habitat change and sea-level rise in tidal marsh environments, particularly for conservation-reliant species such as California rails.

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1. Introduction

Animals living in seasonal or otherwise variable environments often experience temporary limitation in resources leading to reduced survival or reproduction (Elton, 1927; Fretwell, 1972; Payne and Wilson, 1999). These critical periods may create short-term population bottlenecks that influence population dynamics, particularly when seasonal resource limitation increases intra-specific competition or predation (Ekman, 1984; Roy and Thomas, 2003). Resource supplementation using artificial structures is common practice in conservation, particularly for management of birds and game species (Hinsley and Bellamy, 2000; Stoate and Szczyr, 2001). Artificial structures are credited

with increasing populations of waterfowl, osprey (*Pandion haliaetus*), and cavity nesting birds through provision of nest sites (Corrigan et al., 2011; Ewins, 1996; Newton, 1994). Management of Light-footed Ridgway's Rail (*Rallus obsoletus levipes*; formerly Light-footed clapper rail, *Rallus longirostris levipes* Chesser et al., 2014) in Southern California involves floating nest structures to augment reproduction (Zemba, 1990).

Artificial habitats have also been constructed to improve species' survival rates in a variety of terrestrial and aquatic environments. Artificial floating islands are being used to increase water quality and enhance biodiversity (Chang et al., 2014). Artificial floating islands provided as nesting substrate are also used to improve recruitment of black-throated loon (*Gavia arctica*) in Scotland, red-throated loon (*Gavia stellata*) in Finland, and were associated with greater hatching success of Black Terns (*Chlidonias niger*) in Wisconsin (Hancock, 2000; Nummi et al., 2013; Shealer et al., 2006). Hedgerows providing escape cover often increase

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survival of game birds species and promote greater bird abundance and diversity (Hinsley and Bellamy, 2000). Cottontail rabbits (*Silvilagus* sp.) and snowshoe hare (*Lepus americanus*) used supplemental refuge habitats heavily, but with no apparent change in survival rates (Cox et al., 1997). Artificial rocks increased survival and abundance of velvet geckos (*Oedura lesueurii*; Croak et al., 2013). Artificial nesting mounds were used more than expected by freshwater turtles as nesting substrate and nests on artificial mounds had greater hatching success than natural nests (Paterson et al., 2013). Artificial sea grass habitats decreased efficiency of predators and increased survival of juvenile walleye pollock (*Theragra chalcogramma*) (Heck and Thoman, 1981; Manatunge et al., 2000; Sogard and Olla, 1993). Rearing fish in artificially vegetated hatchery pools may increase survival after stocking (Einfalt et al., 2013). Submerged reef structures may be the most globally widespread artificial habitat enhancement (Seaman, 2000). As a management tool, artificial habitats may be a more attractive option than restoration of natural habitat due to the relative flexibility of implementing actions and the immediacy of resultant change in habitat condition or characteristics. However, artificial habitats may also create ecological traps if predators cue into them and increase their overall capture efficiency (Shochat et al., 2005). Alternatively, avoidance of artificial habitats by target species may result in no net population change and result in costly conservation actions with no tangible results (Smith and Rule, 2002).

The consequences of climate change, particularly sea level rise, are likely to decrease the ability of natural habitats to provide salt marsh species with refuge cover. Much of the California coast is projected to experience 42–167 cm of sea level rise this century (National Research Council, 2012). The natural processes that maintain zones of marsh vegetation, accretion of sediment and organic matter, are not likely to keep pace with this rise. In San Francisco Bay 96% of the tidal marsh is projected to convert to mudflat by 2100 (Takekawa et al., 2013). Saltmarsh habitats which do remain will be more frequently inundated and by higher water levels, jeopardizing terrestrial intertidal species that are unable to cope with the combined effects of habitat loss, habitat conversion, and compression of the vegetated zone between hardscaped (e.g., levees) upper boundaries and rising tides (Erwin et al., 2006;



Fig. 1. Photograph of floating artificial island. Floating artificial islands made of a recycled plastic polymer and high density foam were installed at Arrowhead Marsh, Oakland, CA in September 2010 and monitored using time elapse and motion triggered cameras through March 2012. Woven palm leaves attached to a PVC frame provided vertical and lateral cover. Each island was anchored just off the marsh plain using augur anchors and braided nylon rope of sufficient length to allow floatation during maximum tide heights (2.5 m). Water level in photo is approximately 1.2 m for comparison.

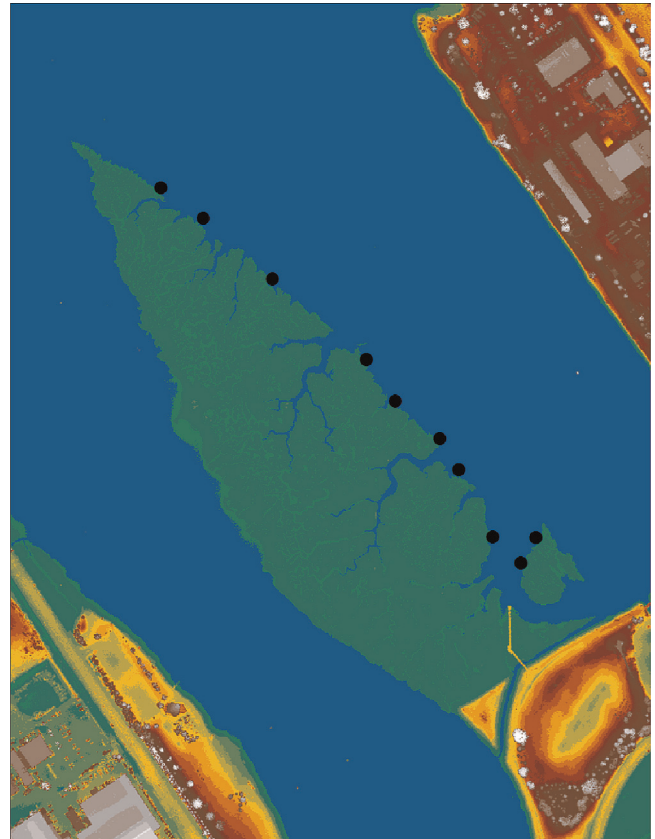


Fig. 2. Map depicting locations of floating artificial islands. Ten floating artificial islands (black circles) were deployed on the northeastern shoreline of Arrowhead Marsh in San Leandro Bay Oakland, California in September 2010. Ground elevations below mean sea level indicated in blue, and above mean higher high water in yellow to white.

Flick et al., 2003). San Francisco Bay currently contains the greatest amount of estuarine saltmarsh along the Pacific Coast (Josselyn, 1983; Nichols et al., 1986) despite the loss, fragmentation, or conversion of 80% of this critical habitat (Takekawa et al., 2006). Historic filling and urban expansion from adjacent upland habitats are likely to have affected the highest elevation marshlands, resulting in disproportionate loss of historic tidal refuge habitat and leading to the potential shortage of contemporary refuge habitat (Overton et al., 2014). Lack of tidal refuge habitat is particularly problematic for species like the California Ridgway's rail (*R. obsoletus obsoletus*; formerly *R. longirostris obsoletus*, the California clapper rail Chesser et al., 2014; hereafter California rail) and California black rail (*Laterallus jamaicensis coturniculus*) that have small ranges and highly fragmented populations.

The California rail is particularly sensitive to availability of tidal refuge habitats. The state and federally endangered California rail is a tidal-marsh obligate species that inhabits primarily lower elevation tidal salt and brackish marshes in San Francisco Bay California (Albertson and Evens, 2000; Gill, 1979) and is dependent on refuge cover during high tides for protection from predation. Habitat loss and fragmentation are the major contributors to California rail endangerment (Albertson, 1995; U.S. Fish and Wildlife Service, 2010). Radio-telemetry studies found that California rail survival rates were lowest when tide heights were greatest and during the winter when much of the intertidal vegetation used as refuge habitat (e.g., *Spartina* sp.) had senesced (Albertson, 1995; Overton et al., 2014). An invasive hybrid plant, *Spartina foliosa* x *alterniflora*, which grows taller and more densely than native vegetation, increased California rail survival rates

before the plants were treated with herbicide as part of an eradication effort (Overton et al., 2014). Spread of hybrid *Spartina* within San Francisco Bay reversed the effects of refuge limitation on California rail populations and resulted in increasing populations prior to the on-going eradication program (McBroom 2012; Overton 2013). The low abundance of California rail populations, degraded and fragmented remaining marshland, and additional predicted habitat loss in the future due to continued sea-level rise (Takekawa et al., 2013) imply that on-going management will be necessary to maintain this species (U.S. Fish and Wildlife Service, 2010). Since elimination of these threats is not feasible, the California rail is likely to remain a conservation-reliant species maintained through continued management for the foreseeable future (Scott et al., 2005, 2010). One proposed strategy to mitigate low seasonal survival in California rails involves providing natural and artificial refuge habitats during the winter. However, evaluating use of these artificial habitats is crucial to understanding their effectiveness as a conservation tool (Smith and Rule, 2002).

The limited availability of current and future tidal refuge habitat may be alleviated through habitat supplementation, either using artificial material or through intensive restoration. For artificial habitats to be an effective conservation tool, they must be used by the species of interest and improve demographic rates. Our goal was to better understand the importance of tidal refuge habitats for saltmarsh obligate species through habitat supplementation. Specifically, we evaluated California rail use of supplemental tidal refuge habitat in the form of artificial floating islands. It is often difficult to assess whether management actions such as supplementing habitat result in change of demographic rates for endangered species with low population sizes and when both legal protections and logistical challenges preclude intensive study. Therefore, we focused our assessments on patterns of artificial island use by California rails with the recognition that habitat use does not necessarily indicate the sufficiency of habitat to promote sustaining populations. Our specific objectives were to examine whether: (1) use of artificial islands was related to tide height; and (2) use of artificial islands increased through time in relation to vegetation senescence, California rail habituation, or seasonal relaxation of territoriality.

2. Materials and methods

We used documented California rail use of artificial floating islands using time-lapse photo documentation at Arrowhead Marsh, a 10 ha intertidal marsh managed by the East Bay Regional Park District in San Leandro Bay Oakland, California, USA. Arrowhead Marsh contains vegetation typical of South San Francisco Bay saltmarshes. Groundcover is a mixture of *Sarcocornia virginica*, *Distichlis spicata*, *Frankenia grandifolia*, and *Jaumea carnosa*. The primary species providing escape and refuge cover for California rails are *Grindelia stricta* and hybrid *Spartina*, with some *Sarcocornia* plants growing tall enough to provide cover (Harvey, 1988; Zembal et al., 1989). Arrowhead Marsh also supports one of the highest known densities of California rails where concurrent population surveys indicated 41–50 California rails were present at Arrowhead Marsh in 2010 and 31–36 birds in 2011 (McBroom, 2012). Arrowhead Marsh had been the focus of a phased eradication of non-native hybrid *Spartina* from 2007 to 2009 (Hogle, 2011). Herbicide treatments to eradicate *Spartina* in a portion of the marsh began in 2007 but were suspended in 2010 due to uncertainty regarding how vegetation alteration impacted California rails. The relatively low elevation of Arrowhead Marsh and habitat change brought about from herbicide application resulted in limitation of tidal refuge habitat, particularly during the winter when vegetation senesced (Overton et al., 2014).

Ten 1.5 × 2.1 m commercially-available, artificial islands made of recycled plastic and high density foam (Biohaven[®]; Floating Islands West, LLC, Mokelumne Hill, CA) were deployed in September 2010 along the northeastern edge of Arrowhead Marsh in San Leandro Bay Oakland, CA, USA (Figs. 1 and 2). Islands were tethered with auger anchors and nylon rope of sufficient length to allow the islands to float during the highest tides but short enough to limit lateral movement. This ensured that the islands provided the same quantity of refuge habitat at all stages of tidal inundation, whereas natural habitats provided less refuge habitat as tidal inundation increased. Each island was covered with 1.2 m tall woven-palm screens affixed to a 0.75 m tall PVC frame secured to the island. The extra length of palm screen was overlapped and affixed to the other side, creating a completely enclosed structure with lateral and overhead cover. Openings allowed access for rails on all sides and through the top of the screen but were designed to limit access by avian and mammalian predators.

An infrared camera capable of taking time-elapsd and motion triggered photographs (Reconyx HC600, Holmen, WI, USA) was placed on a small wooden block affixed inside the cover of each island. From 1st October 2010 to 15th March 2011 (year 1) the cameras took one photograph each minute. Cameras could also be triggered by a passive infra-red motion sensor to take a series of photographs at 1 frame per second for 10 s. Combined, these time-lapse and motion-sensed triggers resulted in 2.1 million photographs during year 1. In the second winter, we lengthened the time-elapse interval to five minutes during 1st November 2011 to 15th March 2012 (year 2) and took 319,646 photographs. Because of variability between the motion-sensing capability of different cameras, motion-triggered photographs were used only to help interpret photos and not to quantify use. Each photograph was scored for presence or absence, species identification, and number of individuals present in the photograph. We interpolated local tide height at the time each photograph was taken from 6-min interval tide-height data collected at the NOAA-operated Alameda tide gauge 8 km northwest from the study area (National Oceanic and Atmospheric Administration, 2011).

Artificial island use by California rails was recorded as a binary (presence/absence) dependent variable and we modeled the probability of island use by California rails in each year with a logistic generalized estimating equation (GEE; Koper and Manseau, 2009). GEE models account for covariance within clusters of measurements. A cluster is the analysis unit containing multiple repeated measures, which in our models equate to the serial autocorrelation expected with our use of time-lapse photography. We considered use of islands to be independent of each other and sequential photoperiods also to be independent; therefore, our clusters were identified by an interaction term specifying an island on a given day during a given photoperiod. Autocorrelation structure within each cluster was modelled to follow an autoregressive-lag 1 pattern and “sandwich” estimates were used to provide robust and unbiased variance estimates of parameters (Koper and Manseau, 2009). The number of clusters (effective sample size) present in our data was 4523 in 2010–2011 and 3315 in 2011–2012.

Our employment of systematic random sampling to monitor islands (e.g., time-lapse) and high rates of island use by California rails were sufficient for GEE to provide unbiased estimates of the resource selection probability function (RSPF; Keating and Cherry, 2004). That is, our sampling did not bias the probability of use conditioned on habitat covariates and a straightforward interpretation of the RSPF for artificial floating islands was possible (Manly et al., 2002). Fixed effects used in models were tide height, days since island deployment, light cycle (day versus night), and an interaction of tide height with light cycle. The goodness-of-fit of each years' model containing all covariates was evaluated relative to a null

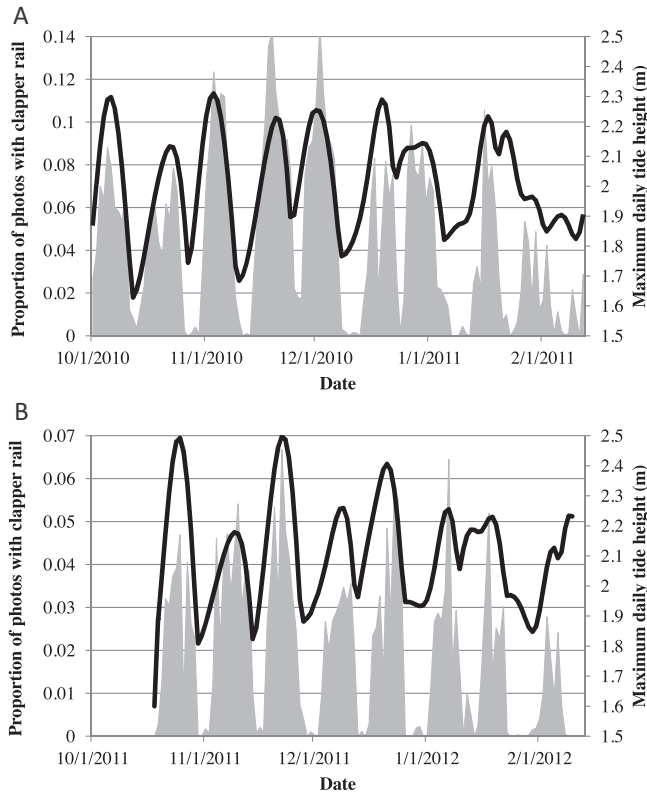


Fig. 3. Comparison of artificial island use and tide height. Observed California Ridgway's rail use of artificial islands (grey bars) and maximum tide height above mean lower low water (black line) at Arrowhead Marsh during the winter of 2010–2011 (A) and 2011–2012 (B).

model containing no covariates, but assuming autocorrelated error structure, with a likelihood ratio test using the quasi-likelihood Akaike's Information Criterion for each model (Pan, 2001).

We documented change in marsh vegetation structure during each winter from 50 randomly placed 1 m² quadrats. Quadrant locations were selected using the "Generate Random Points Tool" within Hawth's Tools v.3.27 (www.spatial ecology.com) operating within ArcGIS 9.2 (ESRI, Redlands, CA). The extent of intertidal habitat dominated by *Spartina* was digitized from orthorectified aerial photographs and 50 random locations were selected from within this habitat under the constraint that any point occurs >2 m from a neighboring point. Vegetation height within each quadrat was measured in September, November, February, and April of the winter of 2010–2011 and in December, February, and April during the winter of 2011–2012. These measurements were used only to describe the broad pattern of tidal refuge habitat available within Arrowhead Marsh. Quantifying the availability of California rail habitat is difficult because the species is territorial and intraspecific competition may make habitat unavailable. Furthermore, it was infeasible to obtain vegetation measurements within the specific territories of rails which used the islands. Therefore, vegetation heights were not used as covariates in models estimating island use. We used nonparametric Kruskal–Wallis tests to compare the distributions of vegetation heights in December 2010 to vegetation heights in January 2012, February 2011–February 2012, and April 2011–April 2012.

Lastly, we compared the estimated probability of artificial floating island use with the availability of islands as a proportion of total habitat available (i.e., the artificial and natural habitat combined). The RSPF provides a ranking of the importance of each habitat type (natural vs. artificial) relative to the availability of that habitat (Keating and Cherry, 2004). The extent of natural habitat at

Arrowhead (~19.7 ha) was estimated from orthorectified aerial photography where intertidal vegetation was digitized by hand. The extent of artificial habitats at Arrowhead was quantified from the surface area of all 10 artificial islands (31.5 m²). Therefore, at Arrowhead Marsh, the proportion of artificial island habitats was 0.016% and RSPF values above this threshold indicated selection of artificial habitats.

3. Results

Cameras recorded California rails 85,582 times (4.1%) in year 1 and 6370 times (2.0%) in year 2. Use of islands by a single rail was most common (95.8%), but presumptively pair-bonded rails also simultaneously used islands (4.1%). Photographs captured a single instance of three rails briefly occurring on an island.

Our inferential models containing tide height, photoperiod, and temporal covariates of California rail use of artificial islands significantly outperformed null models without covariates as indicated by quasi-likelihood ratio tests (2010–2011: QLR $\chi^2 = 40,075$, d.f. = 4, $p < 0.001$; 2011–2012: QLR $\chi^2 = 20929$, d. f. = 4, $p < 0.001$). Autocorrelation of island use was high (correlation parameter = 0.937 for both years), but standard errors adjusted for this correlation still showed significant effects.

The influence of tide height on artificial floating island use by California rails differed between years (Fig. 3) and between photoperiods (Fig. 4) but the probability of use was greater than the availability of the artificial habitat at almost any tide level (Fig. 5). During year 2, use of artificial islands was lower than in year 1 (Table 1); however, tide level increased the odds of daytime

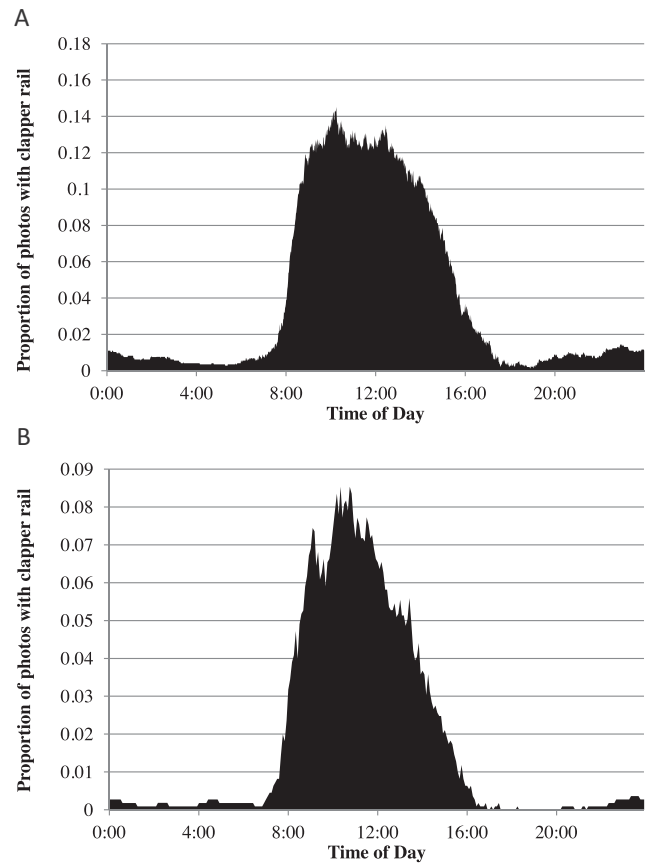


Fig. 4. Artificial island use across time of day. Observed California Ridgway's rail use of ten artificial floating islands at Arrowhead Marsh during the winters of 2010–2011 (A) and 2011–2012 (B). During both winters California rail use of islands occurred mostly during daylight hours.

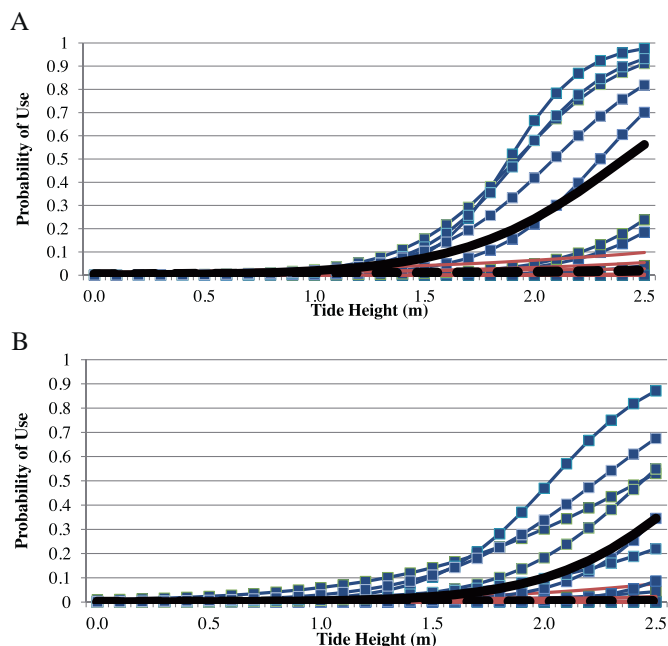


Fig. 5. Probability of artificial island use. Probability of artificial refuge island use between (A) October 2010 and March 2011 and (B) November 2011 and March 2012 by California Ridgway's rails during the day (solid black line) and night (dashed black line) relative to tidal height and estimated using generalized estimating equations accounting for autocorrelation. Logistic multiple regressions for individual islands are presented to demonstrate variability in individual island use (daytime = blue lines with squares; nighttime = red lines). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

artificial island use more in year 2 than year 1. Every meter of tidal inundation increased the odds of island use 1610% in year 1 and 2271% in year 2. The estimated probability of daytime island use at mean higher high water (2.2 m), holding other variables at mean values, was 35.8% in year 1 and 17.1% in year 2.

Nighttime use of islands was comparatively low in both years (Fig. 4; Table 1). Linear contrast of model parameters indicated that tide level did not significantly change the odds of use in either year 1 (odds ratio 1.93; $p=0.054$) or year 2 (odds ratio: 2.46, $p=0.139$). The odds of an island being used increased by 33% every 90 days during year 1 (Table 1). However, the

Table 1

Parameter estimates from logistic generalized estimating equations modelling. Parameter estimates from logistic generalized estimating equations modelling California Ridgway's rail use of artificial islands from October 2010 to March 2011 (A; $n=2,095,267$) and from November 2011 to March 2012 (B; $n=319,646$). Models included an autoregressive (AR1) error structure and a sandwich variance estimator was used to calculate standard errors. Cluster groups used to fit marginal (population-level) generalized linear models while accounting for autocorrelation included island, photoperiod and date. Photoperiod effects were modeled as factors and parameters for Nighttime represented the estimated difference from Daytime factors.

Effect	Estimate	Std. error	Wald	Pr(> z)
Intercept (day)	-6.99	0.210	1106.4	<0.001
Nighttime	1.15	0.113	14.4	<0.001
Tide	2.78	0.303	609.4	<0.001
Tide.nighttime	-2.12	0.194	119.7	<0.001
Date	0.00321	0.00082	15.3	<0.001
Effect	Estimate	Std. error	Wald	Pr(> z)
Intercept (day)	-8.19	0.242	1149.06	<0.001
Nighttime	1.29	0.769	2.83	0.093
Tide	3.12	0.109	828.29	<0.001
Tide.nighttime	-2.46	0.485	25.6	<0.001
Date	-0.00283	0.0021	1.86	0.173

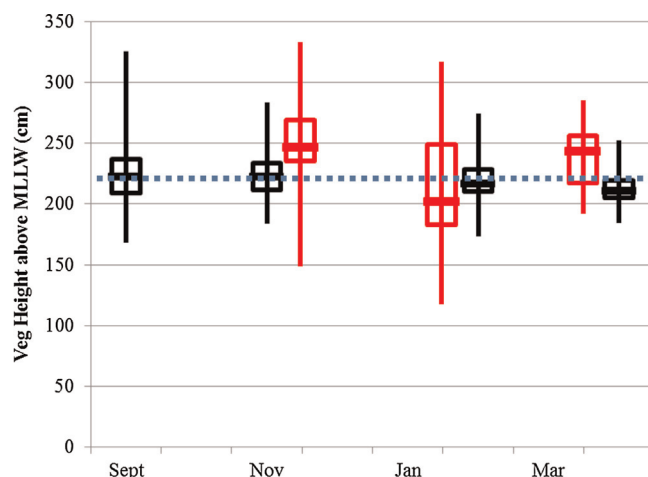


Fig. 6. Vegetation height. Vegetation height relative to mean lower low water at Arrowhead Marsh during the winter of 2010–11 (black) and 2011–12 (red). Mean higher high water indicated by dashed blue line. Box plots indicate 25% and 75% quantiles with median value in bold. Whiskers indicate minimum and maximum values. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

temporal trend through the winter in year 2 was much lower and the odds of use did not significantly change with time (Table 1). Substantial variation in use of individual islands occurred (Fig. 5).

Vegetation structure differed between years during December/January (Kruskal–Wallis $\chi^2=28.61$, d.f.=1, $p<0.001$) and April (Kruskal–Wallis $\chi^2=34.5794$, d.f.=1, $p<0.001$) but not during February (Kruskal–Wallis $\chi^2=0.7787$, d.f.=1, $p<0.3776$). Vegetation height was typically higher in year 2 and more vegetation was available as refuge above MHHW than in year 1 (Fig. 6).

Selection for artificial floating islands was indicated when the resource selection probability function (RSPF) estimated from the GEE model exceeded the availability of artificial islands as a proportion of total habitat (0.016%). The only period for which selection for artificial islands was not evident occurred during year 2 when tides were at or below mean lower low water. When tide levels reached the mean elevation of the marsh plain (1.6 m; Overton et al., 2014), the RSPF during the day was 596 times and 349 times the availability of artificial habitats (0.016%) in year 1 and year 2, respectively. Equivalent tides at night only provided RSPFs that were 64 times (year 1) and 16 times (year 2) the availability of artificial habitats.

4. Discussion

Tidal refuge habitat is a critical component of salt marshes and limitations in its availability may have repercussions, particularly for rare localized species. We suspected that availability of tidal refuge at Arrowhead Marsh was limited due to both recent habitat changes (hybrid *Spartina* eradication) and longer-term changes in relative sea level (Flick et al., 2003). Resident populations of California rail also exhibited survival rate patterns consistent with habitat limitation during high tides and winter (Overton et al., 2014). Our use of artificial floating islands as supplemental tidal refuge habitat provided a unique opportunity to assess the conditions under which an endangered salt marsh obligate species used such habitats.

Two environmental conditions influenced use of artificial islands by California rails during both years: tide level and photoperiod. We anticipated that tide level would be a predictor of artificial island use by rails since tidal refuge habitat becomes

more limited at higher tide levels (Table 1). However, we did not anticipate the marked difference in use of artificial islands between daylight and nighttime periods (Table 1). We also did not expect that tide level would not influence use of islands during the nighttime (Table 1). We suggest two reasons why selection of tidal refuge habitat by obligate salt marsh species would differ between photoperiods. Firstly, there could be a delay between when habitats are selected and when need for refuge is realized. Winter tides, in San Francisco Bay are highest during the full and new moons and tide levels peak near the middle of the night when rails are mostly sedentary (Rush et al., 2012). During these periods, lowest tide levels occur near dawn and dusk when rails most actively forage (Nidzieko, 2010; Zembal et al., 1989). Selection of habitat at dusk does not reflect the need for refuge habitat once tides rise a few hours later. California rails may have chosen alternative habitat to the islands because there was no need for tidal refuge habitat at dusk or the islands could not be located at night. Secondly, the nocturnal predator community at Arrowhead Marsh may be absent or unable to access marshlands during tidal inundation. Avian raptors frequently occur, and are the primary cause of mortality in California rails, at Arrowhead Marsh (USGS, unpublished data). Nocturnal avian predators that could elicit refuge-seeking behavior may not be present at Arrowhead Marsh, although owls are predators of California rails elsewhere (Cottam and Nelson 1937; Johnston 1956). Anti-predator behavior in California rails may itself be light-dependent and the birds may not actively seek refuge in low light conditions if visual predators are absent. This type of plasticity in anti-predator behavior, refuge selection during daylight but not at night, is unknown for California rails and may vary according to composition of the predator community as well as with available habitats.

The probability of artificial island use by California rails also differed between years and was higher during year 1. Variation in the amount of naturally occurring tidal refuge habitat may account for these patterns. The tallest vegetation in San Francisco Bay salt marshes is usually native *Spartina foliosa* or hybrid *Spartina*, both of which senesce and degrade during the winter (Overton et al., 2014). Progressive limitation in refuge cover could result in increased use of artificial habitats by salt marsh species during the winter. During year 2, the availability of natural refuge habitat was greater than year 1 and more vegetation remained above mean high water (Fig. 6). In addition, population density of rails, as indexed by call count surveys, decreased between 2010 and 2011 (McBroom, 2012). Fewer individuals within the marsh may also have resulted in lower probability of artificial island use during the second year.

There is increasing concern about the fate of tidal marsh habitats and constituent species in the face of projected sea-level rise (Thorne et al., 2013; Erwin et al., 2006). Past land use changes that prevent the landward “migration” of salt marsh and reduce resilience to climate change have intensified these concerns. In highly developed areas, such as San Francisco Bay species occupying salt marsh are expected to become reliant on continual conservation actions to enable their persistence. Restoration and rehabilitation of salt marsh habitats may be able to compensate for the projected effects of climate change but only if restoration provides the ecological functions needed by species. Escape cover during tidal inundation is one such function that directly influences survival rates of tidal marsh species (Overton et al., 2014). Habitats which provide this function may be disproportionately affected by past land use decisions and future environmental conditions. The utility of artificial habitats as a short-term tool to mitigate these effects may be constrained by the behavior of the target species, presence and abundance of sympatric species, and existing habitat condition.

Species' behavior and the conditions under which a species selects habitats should be understood to develop an efficient and effective conservation action. For example, artificial islands almost never included more than a pair of California rails despite being large enough to hold 6 or more individuals. A single instance occurred when a third individual, distinguished through external markers used in a separate study, briefly occupied an artificial island before one of the birds already present chased it away. During the highest tides, Ridgway's and clapper rails (*R. crepitans*) frequently occur in groups when refuge cover is limited in native marshes (Sibley, 1955; Stone, 1937; Zembal et al., 1989). This lies in contrast to “typical” behavior during other seasons. Territorial contest competition for space governs Ridgway's and clapper rail intraspecific interactions during nesting and brood-rearing periods (Rush et al., 2012). During the short-duration periods when high tides flood the majority of marsh vegetation, scramble competition for refuge habitat is more indicative of behavior. The high density of birds at Arrowhead Marsh may mean that scramble competition for space during high tides limits survival during the winter (Overton et al., 2014). In order for artificial floating islands to alleviate this limitation, the artificial habitats must both be used and provide higher survival probability. Our results clearly indicate that artificial floating islands are used. However, effects on survival rates may be difficult to ascertain due to the unexpected contest competition evident in patterns of artificial island use (i.e., only presumed mated pairs occupying islands). A case-control study would be the most efficient means to detect the effects that artificial habitat had on survival rates.

The abundance, diversity, and identity of species other than the California rail that are present in salt marsh may also influence the efficacy of artificial habitats. As we previously noted, the presence or absence of specific types of predators (e.g., absence of owls) may have influenced temporal patterns of artificial habitat use by California rails. Specific predators (e.g., corvids) may cue in on artificial habitats which could become ecological traps (Shochat et al., 2005) if survival rates actually decrease relative to natural habitats. Large artificial habitats could provide protection from tidal inundation for mammalian predators and facilitate their continual occupancy of marshes that otherwise would be inhospitable. Additionally, use of artificial habitats by non-target species may dissuade use by the salt marsh obligates for which they are intended. During the first winter of our study, other species infrequently used the islands and were seen on only 2325 (0.1%) of photographs. However, during the second winter, non-target species use increased to 7% (21,814) of photographs and was largely due to overnight roosting by American coots (*Fulica americana*). Given the relatively low rate of use by California rails during the night in either study year, the use observed by coots may not have influenced California rail use. However, this observation illustrates the potential for artificial habitats to be made unavailable to salt marsh species due to occupancy by other species. Other non-target species that used the islands included: Sora (*Pozana carolina*), Canada Goose (*Branta canadensis*), Mallard (*Anas platyrhynchos*), Forster's tern (*Sterna forsteri*), California Gull (*Larus californicus*), Marsh Wren (*Cistothorus palustris*), Salt Marsh Song Sparrow (*Melospiza melodia*), White-crowned Sparrow (*Zonotrichia leucophrys*), Black Phoebe (*Sayornis nigricans*), Snowy Egret (*Egretta thula*), Great Blue Heron (*Ardea herodias*), Norway Rat (*Rattus norvegicus*) and Muskrat (*Ondatra zibethicus*).

The condition of existing habitat, including spatial arrangement of natural tidal refuge, is another factor that may influence the effectiveness of artificial habitats and restoration. Significant variation in the frequency of use by California rails occurred among the islands (Fig. 5). While not a specific objective of our project, we note that rails were more frequently observed on islands that were further from the adjacent upland areas. The

marshland-upland transition zone is often minimal within the highly urbanized San Francisco estuary and is limited to levees that protect adjacent development. The transition zone at Arrowhead Marsh has been the focus of a rehabilitation project to restore native vegetation. California rails and other salt marsh species are known to use such zones as refuge habitats during extreme tidal inundation (Garcia 1995). Upland transition zones also provide access to marshland for terrestrial predators. Few radio-marked California rail mortalities at Arrowhead Marsh could be attributed to mammalian predators (USGS, unpublished data). Three factors could explain potential spatial differences in island use: variation in rail density, variation in natural habitat availability, and variation in selection of habitats by rails. Rail density near the upland transition zone is lower and the increased probability of artificial island use further from the upland could be a result of fewer rails occurring near the artificial islands. The availability of natural tidal refuge cover could vary through Arrowhead Marsh if more naturally occurring tidal refuge habitat was available near the upland transition zone, lower use of artificial island could result. However, elevation maps that depict refuge potential in Arrowhead Marsh were delineated using LiDAR data collected in February 2010 and do not indicate that more refuge was available near the transition zone (USGS, unpublished data). Similar spatial data is not available concurrent with our study, but we doubt the spatial arrangement of tidal refuge habitat changed substantially. Lastly, natural refuge habitat occurring within the upland transition zone may have been preferred by California rails leading to low probability of artificial habitat use. It may be possible to use artificial islands to test the ecological role of different habitat conditions, including presence of alternate refuge habitat types, on the habitat requirements of salt marsh species.

Some San Francisco Bay salt marshes may currently be limited in refuge habitat. Existing marshes may be able to cope with the projected rise in mean sea level through transgression into upland areas or accretion of sediments and organic matter (Gedan et al., 2011; Kirwan and Megoñigal, 2013; Morris et al., 2002). However, within the highly urbanized San Francisco Estuary, this is not assured and reduction in tidal marsh habitat is expected by the end of the century (Schile et al., 2014; Stralberg et al., 2011; Takekawa et al., 2013). Sea-level rise projections also suggest that tidal range will increase (Flick et al., 2003). This would have disproportionate effects on tidal refuge habitat and create additional pressures on populations of salt marsh species. Supplementation of tidal refuge habitats could alleviate short-term demographic bottlenecks and may be critical for long-term population persistence of salt marsh obligate species. Ongoing and future habitat management and restoration in San Francisco Bay should consider provisioning refuge habitats for California rails and other endemic marsh species while accounting for patterns in species behavior and constituent community assemblages.

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