Title
Investigation into potential range shifts of murrelet species in the Southern California Current Ecosystem

Authors
Halliman, Karina
Russell, Tammy
Vernet, Maria

Publication Date
2022-06-15

Peer reviewed

STUDENT PAPER 2

Investigation into potential range shifts of murrelet species in the Southern California Current Ecosystem

Karina Halliman

ABSTRACT

Anthropogenic climate change is warming our oceans and thus has the potential to dramatically alter marine ecosystems. Recent ocean temperatures have been shown to impact the distribution and availability of prey species, which may lead to periodic or permanent range shifts of the predators relying on them. Since seabirds are solely dependent on marine prey, changes in seabirds' distribution may be valuable alerts for ecosystem health. We expand upon previous investigations of range and seabird community composition within the California Current Ecosystem (CCE) form 1980-2017 by selecting a "warm water" and "cool water" seabird species. We investigated these potential trends in Craveri's murrelets (CRMU), the "warm water" species, and ancient murrelets (ANMU), the "cool water" species, as their northern and southern range, respectively, overlap in the southern CCE region. They are comparable in size, natural history, and prey type. We hypothesized that the trends in their distribution would reflect the northward expansion of warm water over time and periods of warm water associated with El Niño Southern Oscillation (ENSO). We expected CRMUs to increase in frequency and northward distribution over time and during El Niño events. For ANMUs, we expected to see a decrease in their frequency and a shift northward over time and with El Niño events. We calculated multiple linear regression models to analyze the relationships between species density (frequency of sightings/km2) with latitude, upwelling, and year. We found a decrease in density of both species and that latitude was the only significant predictor for both species' density. This research will provide a foundation for future investigations of seabird range shifts in the CCE and assist in further understanding changes in upwelling ecosystems.

INTRODUCTION

Anthropogenic climate change is dramatically altering ecosystems. The marine environment's dynamic and highly interconnected food webs are especially vulnerable to these impacts, as the global average sea surface temperature (SST) warmed at an average of 0.13° C per decade over the last century (NOAA 2021). These warming waters have been documented to disrupt ocean systems and subsequently the distribution and availability of prey for upper trophic level predators (Hyrenbach and Veit 2003; Piatt et al. 2020; Velarde et al. 2015). Along with regional ocean warming, climate change may also induce more frequent and severe global El Niño events, which decrease the amount of nutrients brought to surface waters, resulting in lower productivity in upwelling ecosystems (Gremillet and Boulinier 2009; Hyrenbach and Veit 2003). The changing physical dynamics are likely to impact marine predators, such as seabirds, by decreasing the availability of pelagic fishes and zooplankton resulting in populations dying off (Gremillet and Boulinier 2009). Seabirds are one of the most threatened birds in the world, with 69.7% of monitored seabird populations worldwide having decreased between 1950 and 2010. Seabirds are especially vulnerable to warm water impacts (Paleczny et al. 2015). For example, an extreme warm water event occurred off the west coast of the U.S. between 2014- 2016, (The Blob) which impacted water temperatures from Alaska to California (Piatt et al. 2020). One study found that the impacts from this event on ocean life were complex and included a decrease in phytoplankton biomass and an increase in metabolic rate of ectotherm fish (Piatt et al. 2020). The shifts impacted higher trophic level species through decreased prey availability, increased competition with fish predators, and less nutritious prey. The impacts led to starvation in common murres, an important marine predator, and resulted in a significant die-off event (Piatt et al. 2020).

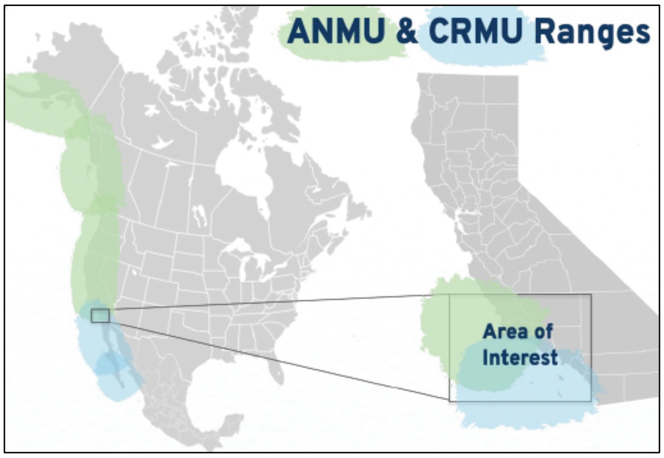
The California Current is a highly productive system that contains vital foraging habitats for many resident and migratory seabird species. Between 1987 and 1998, a documented shift from a 'high-productivity' to a 'low-productivity' ecosystem was characterized by an increase in thermocline depth (Hyrenbach and Veit 2003). The thermocline is the point at which there is a steep temperature gradient, from warm to cold water. (Hyrenbach and Veit 2003). When the thermocline depth increases, there is higher stratification which inhibits the strength of the upwelling. The decreased upwelling results in reduction of nutrients, leading to smaller phytoplankton outcompeting larger phytoplankton. The shift to smaller phytoplankton can have significant impacts on the ecosystem by extending the length of the food chain, decreasing trophic transfer efficiency, and results in less nutritious prey (Hyrenbach and Veit 2003). Impacts of overall increased SST and increased El Niño events are likely to alter the distribution of forage fishes and other crucial marine prey for seabirds (Wingfield et al. 2015). These shifts in prey distribution may lead to periodic or permanent range shifts of species reliant on them. Range shifts are changes in a species' distribution which can be directional shifts, expansions, or compressions (Wingfield et al. 2015). For example, elegant terns have been found to shift northward to cooler , more productive waters during warm water years, likely due to rising SSTs and a reduction of sardines in their previous range (Velarde et al. 2015).

Current research on global range shifts varies in explanation and further investigation is needed to explore the multivariable issue of how climate change is impacting ocean ecosystems. Pinsky et al. 2013 shows that climate velocities, the change in rate and direction that similar temperature isotherms make, influence the rate and direction of marine species range shifts. However, some researchers believe that seabirds shifting their range solely because of physical variability is too simplistic. Instead, shifts may be due to changes in prey distribution and overall ocean productivity (Hyrenbach and Veit 2003). To investigate potential range shifts occurring in the California Current ecosystem (CCE), we selected two Synthliboramphus murrelet species, Craveri's murrelets (CRMU, S. craveri) and ancient murrelets (ANMU, S. antiquus). The northern and southern extent of their ranges overlap in the southern CCE region. We chose the region from the U.S. Mexico border to central California because it is where CRMU northern range and ANMU southern range converge (figure 1). These two species are also comparable in their size, natural history, and prey type; therefore, the two species present an opportunity to compare how climate change and warm water events affect the distribution of a "cool water" and "warm water" species.

CRMUs are classified as vulnerable and their population is decreasing (BirdLife International 2020). They primarily feed on larval fish, small squid, and crustaceans at the edge of the continental shelf (DeWeese and Anderson 1976; Vermeer et al. 1985). This species is endemic to Mexico and breeds on islands along the Baja California Peninsula and in the Gulf of California (Everett and Anderson 1991). (figure 2) This species nest in rocks or burrows from early February to March, and then chicks hatch in March to April and are semi-precocial, meaning they hatch at an advanced stage and leave the nest within a few days of hatching (Breese et al. 1993). A significant threat to this species includes invasive species on nesting islands such as cats, rats, and mice. Conservation efforts to support CRMUs have effectively eradicated introduced mammals from islands in the Gulf of California (Aguirre-Muñoz et al. 2018).

FIGURE 1:

Northern extent of CRMU range and Southern extent of ANMU range which overlap in the area of interest



ANMUs are classified as least concern, yet their population is decreasing (BirdLife International 2018). Their main prey are planktonic crustaceans and small larval fishes, which they forage for along the continental shelf (Vermeer et al. 1985). ANMUs breeds on islands, with half of its population breeding in the archipelago of British Columbia. They are found across the Northern Pacific Ocean, including the Russian Pacific coast, islands off China and Korea, the Aleutian Islands, and far south as Southern California coast (Springer et al. 1993). (figure 3) ANMU chicks are also semi-precocial (del Hoyo et al. 1996; Vermeer et al. 1985). Similar to CRMUs, ANMUs face the threat of invasive mammal species on breeding islands. (Audubon 2020). In addition, records show that climate change and severe weather have impacted this species in the past. Specifically, during the 1997- 98 El Niño event, nest abandonment negatively impacted breeding success (Gaston and Smith 2001). Researchers saw a positive correlation between SST in May and chick mass, meaning in years with higher SST, they measured low reproductive success. El Niño influenced breeding failure for this ANMU population, possibly because it caused desertion of nests (Gaston and Smith 2001). Both CRMU and ANMU have many ecological similarities, including the diets of larval fish and crustaceans. In addition, they both nest in burrows on islands and have semi-precocial chicks. Like many other species of seabirds, they face the threats of introduced mammal species at nesting sites and impacts on their prey due to climate change. But these species differ significantly in their distribution, with CRMU in warmer waters and ANMU in cooler regions. Yet, the northern and southern extent of their respective ranges overlaps in the southern CCE region, making them ideal subjects for this exploratory research.

To address the impacts of climate change on seabird distribution, we conducted an exploratory analysis investigating how the density and distribution of CRMU and ANMU have changed over time (1980-2017). We hypothesized that the trends in these species' distribution and frequency would match the northward expansion of warm water and periods of warm water associated with El Niño. We expected the CRMUs to increase in the frequency of sightings and see a change in the northward direction over time and during El Niño events because as waters are warming the seabirds will need to travel further north to colder waters to find prey. For ANMUs, we expected to see a decrease in the frequency of sightings and a shift northward over time and with El Niño events, to remain in cooler waters as SSTs increase. Understanding how environmental changes may impact seabird distributions will contribute to ecosystem monitoring and future seabird conservation. nts because as waters are warming the seabirds will need to travel further north to colder waters to find prey. For ANMUs, we expected to see a decrease in the frequency of sightings and a shift northward over time and with El Niño events, to remain in cooler waters as SSTs increase. Understanding howenvironmental changes may impact seabird distributions will contribute to ecosystem monitoring and future seabird conservation.

FIGURE 2:

Craveri's murrelet (Synthliboramphus craveri) distribution. CRMU reside along the Southern Californian coast (light brown) and into the gulf of Mexico where they migrate to breed (dark brown) (BirdLife International 2020).

METHODS

The data consists of at-sea density of seabirds in the California Current Ecosystem collected between 1980 and 2017 using ship-based transect survey methods. See Leirness et al. (in press) for detailed survey and data processing procedures (table 1). Analysis relied upon four atsea surveys. Bird sighting provided by the National Oceanic and Atmospheric Administration's (NOAA) Southwest Fisheries Science Center and surveys conducted by the California Cooperative Oceanic Fisheries Investigations (CalCOFI). These data are a subset of surveys that were combined into a common format for analyses for a previous project (Leirness et al. in press). The area of interest for this study is the area within the Central California to the U.S. Mexico border, which includes the Channel Islands (From 30° N to 40° N, and -126° W to -116° W). We selected this region because it includes the northernmost range for CRMUs and the southernmost range for ANMUs. An analysis was conducted by extracting and statisticaly summarizing the survey data. All data manipulation and statistical analysis were done in R (Version 4.0.2). We used R to create maps for

FIGURE 3:

Distribution of ancient murrelets (Synthliboramphus antiquus). ANMU distribution consists of Northern Californian coast, into Canada, Alaska, and parts of Asia shown in shades of brown (BirdLife International 2020).

TABLE 1: At-sea survey data used for analyses.

	Start Year	End Year
California Current Cetacean and Ecosystem Assessment Survey	2014	2014
Collaborative Survey of Cetacean Abundance and the Pelagic Ecosystem	2005	2005
Oregon, California, and Washington Line-transect Expedition	1996	2008
California Cooperative Oceanic Fisheries Investigations (CalCOFI)	1987	2015

the sightings per year per species and ArcMap (Version 10.7.1) for 1° x 1° grids to display the density of sightings (figure 7). We extracted CRMU and ANMU counts that were within the area of interest (figure 4). We tested for normal distribution of the data and violated the assumption of normality. To overcome the limitations of the high number of zeros in our data, we grouped the data into 4-year bins for the analyses (figure 5). We used a multiple linear regression model to analyze the relationship between the density of both CRMU and ANMU with latitude and year.

We additionally used multiple linear regression models to test for relationships between species density with year and ENSO using the Multivariate ENSO Index (MEI), averaged by year (Wolter n.d.).We used the MEI as it uses five environmental variables: sea level pressure, SST, directional surface winds, and reflected solar radiation in the tropical Pacific (Wolter n.d.). We also compared years of high density with ENSO period (table 2).

RESULTS

To further consider the hypothesis we hypothesized that the trends in these species' distribution and frequency would match the northward expansion of warm water and periods of warm water associated with El Niño. We expected the CRMUs to increase in their frequency of sightings and see a shift in the northward direction over time and during El Niño events. For ANMU, we expected to see a decrease in the frequency of sightings and a shift northward over time and with El Niño events, to remain in cooler waters as SSTs increase. There were 75 total sightings for CRMU and 21 for ANMU throughout 1980–2017. (figure 4). The full dataset consists of the years 1980-2017, but there were no sightings of CRMU and ANMU in 2017, so this year is excluded from the statistical analysis and figures. The average sightings per year since the first sighting in 1987 is 2.6 and 58.2 birds per year for CRMU and ANMU, respectively. In addition, there were 20 years where no sightings occurred for CRMU and 15 years for ANMU within the full dataset (1980-2017). After 2003, we see a gap in sighting for CRMU between 2009 and 2013 ANMU was no longer observed.

TABLE 1:

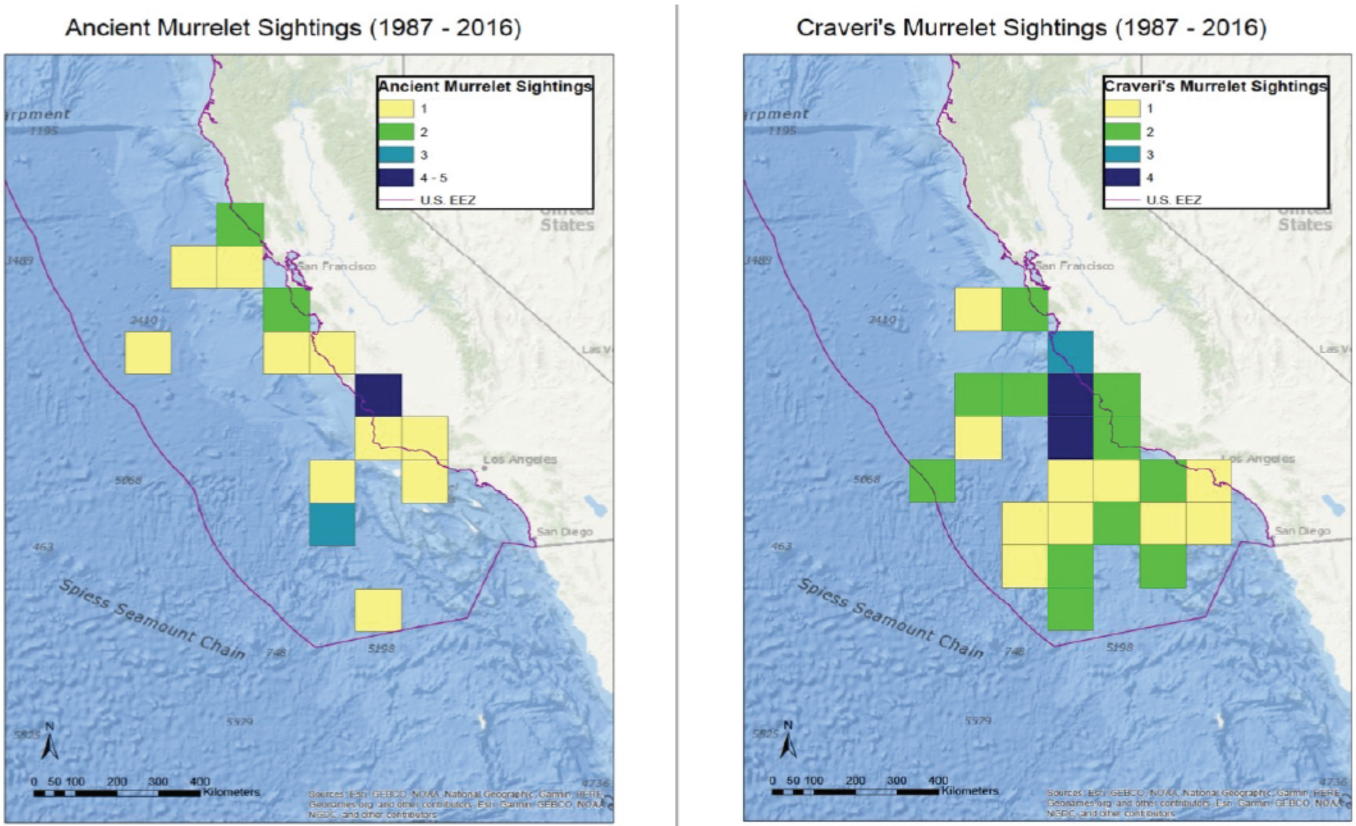
El Niño Southern Oscillation (1984- 2014) (NOAA)

El Niño	La Niña	Neutral
1987	1989	1984- 1986
1988	1999	1990- 1991
1992	2000	1993- 1994
1995	2008	1996- 1997
1998	2011	2001- 2002
2003	2012	2004- 2006
2007		2009
2010		2013- 2014

DISCUSSION

In this analysis, we investigated whether the density and distribution of two species of murrelets, whose ranges converge in the southern CCE, have changed over time (1987-2016) or with ENSO (table 2). We found, contrary to our hypothesis, that both CRMU and ANMU densities have decreased since the mid-1990's. Although we had expected to find a decrease in sightings for ANMU, the decrease of CRMU overtime was unexpected, but is in line with overall seabird trends in the region. Between 1987 to 1994 in the CCE, seabird populations have been shown to have decreased by 40%, which is hypothesized to be driven by the increase in SST in the region (Viet et al. 1996). Because of our data limitations, we could not detect robust trends, but we did find that both species had declined. After 2003 we no longer see ANMU sightings, which is in line with the overall decrease of seabirds' hypothesis (Paleczny et al. 2015). From previous seabird studies, the continued decline in seabird density in this

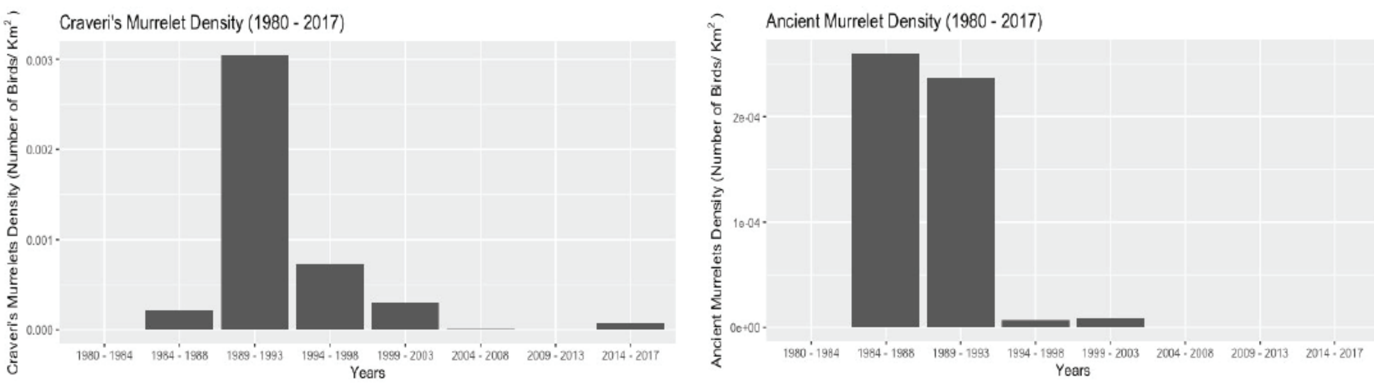
FIGURE 4:



Number of sightings in northernmost range of Craveri's murrelets and southernmost range for ancient murrelets between 1987 and 2016. Maps of sightings show the California coastline with the U.S. exclusive economic zone (EEZ) as the purple line and overall species sightings within 1° x 1° grids. Dark blue grids are 4-5 sightings, teal grids are 3 sightings, green grids are 2 sightings, and yellow grids is 1 sighting (ArcMap Version 10.7.1).

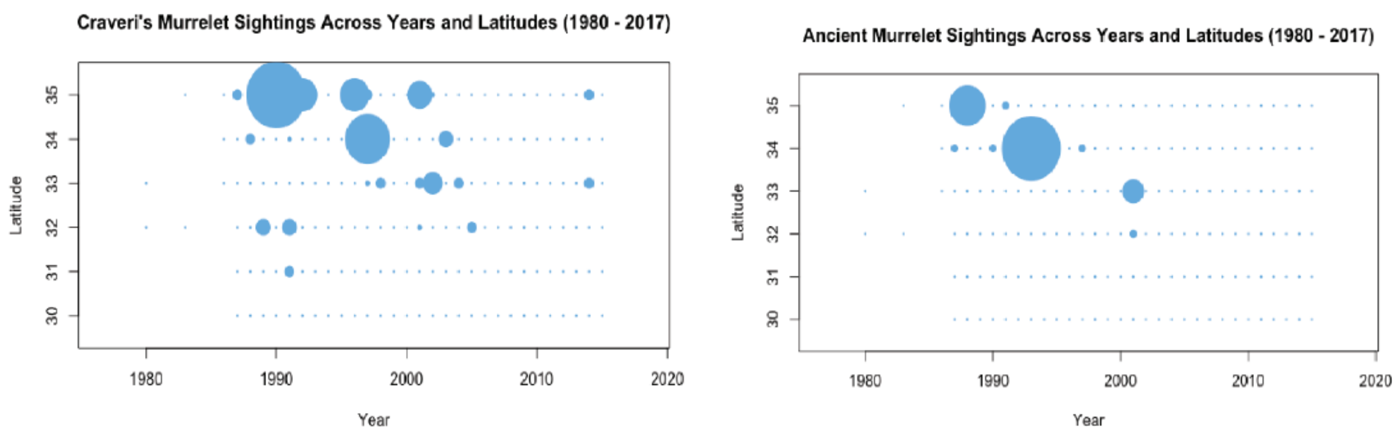
The multiple linear regression for CRMU indicated that the model explained 2.9% of the variance. Latitude contributed significantly to the model (β= 2.0 x10-5, p=0.022), but year did not (β= -2.4 x10-6, p=0.14) (figure 6). The multiple regression for ANMU offered similar results as the model explaining 3.3% of the variance. Latitude contributed significantly to the model (β= 2.3 x10-6, p=0.03), but year did not (β= -3.8 x10-7, p=0.062) (figure 5). The multiple linear regression model on the relationship between CRMU density with MEI and year revealed no significance (Adjusted R2 = -0.00232, F1, 358 = 0.167, p = 0.682). ANMU density with MEI and year also showed no significance (adjusted R2 = -0.00239, F1, 358 = 0.141, p = 0.706). All the models had low adjusted R2 values but low (significant) p values, suggesting a relationship between latitude and species density. Still, there is a high amount of variation in the data that cannot be explained by latitude.

FIGURE 5:



Density (number of birds/km2) of Craveri's (CRMU, top) and ancient murrelets (ANMU, bottom) grouped into 4-year bins (1980 to 2017). Although not significant (p=0.14, Adjusted R2=0.029), there are slightly higher densities seen in earlier years. In later years we see a decrease and no sightings from 2009-2013, but then an occurrence of CRMU again in 2014- 2017. For ANMU, there is no significant trend over time (p=0.062, Adjusted R2=0.033), there are slightly higher densities seen in earlier years, with 1989- 1993 being the highest density and after 2003 there are no sightings recorded (R Version 4.0.2).

FIGURE 6:



The number of Craveri's (CRMU, left) and ancient murrelet (ANMU, right) sightings (1980 to 2017) across latitude. There are more CRMU sightings at higher latitudes and earlier years. There are more ANMU sightings in the earlier years and at higher latitudes. Although not significant, there is a slight negative trend overtime for both species (R Version 4.0.2).

region that we detected is likely due to the continued warming of the waters of the CCE (Hyrenbach and Veit 2003; Velarde et al. 2015). Human influence on marine systems and increased warming have caused alterations to seabirds' habitats. The waters of the California coastal ecosystem are rapidly warming and has increased by 1.24 °C over the past century (Rasmussen et al. 2020). Our observations that both selected species have decreased supports the hypothesis that seabird declines have continued over time and warrants further investigation into overall seabird density trends in the region.

We also investigated if these murrelet species are experiencing range shifts, as periodic range shifts in elegant terns in this region have previously been detected (Velarde et al. 2015). We identified a nonlinear relationship between latitude and species density, and latitude may be an important predictor for species density. The latitudes with the highest densities were between 33 °N to 35 °N and around 37 °N for both species, which coincides with the region around and north of Point Conception and Monterey Bay area. Both regions are areas with more intense upwelling and higher productivity, which may be driving the higher density of seabird sightings from our study (SIMoN 2004; Brzezinski and Washburn 2011). We also tested whether densities were driven by changes in ENSO during our survey period, yet we found no relationship with density and the yearly MEI. Yet, the highest density for CRMU, and the second-highest density for ANMU is seen to be from 1989- 1993. This higher density may have been due to 1989 being a strong La Niña year (NOAA), in which stronger upwelling and increased nutrients support higher productivity in phytoplankton. After this time bin we see a decrease of CRMU sightings over the subsequent years and then none in 2009- 2013. Although in 2014- 2017, we see CRMU sightings, which coincides with the time California's coast experienced an El Niño warm weather event and blob. (NOAA) These observations of CRMU during 2014-17 may be due to birds moving northward from increased warm waters further south, which supports our hypothesis. As more data continues to be collected on birds at sea, we may be able to disentangle these complex relationships and shifts that may be occurring as our oceans continue to change. To further explore the relationship between seabird density and upwelling, a finer scaled upwelling indices would also be beneficial to pick up on smaller spatial scale dynamics.

A potential impact to the results of this study includes the difficulty of differentiating Synthliboramphus murrelets in the region, Scripps (S. scrippsi) and Guadalupe (S. hypoleucus), from CRMU. Like CRMU, these Synthliboramphus murrelets cohabitate together along Southern California and Mexico (Karnovsky et al. 2005; Carter et al. 2005). This potential impact should be considered in future research as it may result in because of the possibility of overcounting or undercounting CRMU because of the inclusion of Scripps and Guadalupe murrelets. A limitation of this study includes the lack of observations of our selected species, which made picking up on trends difficult. Completing more surveys or selecting species that have higher sightings in the region can help mitigate this issue in future research on potential range shifts. In addition, research on seabird prey would add to our understanding of how warm water events and overall increases in SST may be driving shift in seabird distributions. Further monitoring of changes in prey can alert us to food web alterations, such as transitions to smaller, less nutritious prey, or the potential for prey-driven range shifts. In addition, further insight into the complex environmental variables that could be impacting seabird ranges is needed for conservation efforts. This exploratory analysis provides insight into the decrease of seabird density in Southern California and provides direction for future studies exploring this topic. Understanding how environmental changes impact seabird distribution with warm water anomalies and increasing SST will contribute to ecosystem monitoring and future seabird conservation in this region.

CITATIONS

"Ancient Murrelet." Audubon, 22 Oct. 2019, www.audubon.org/field-guide/bird/ancient-murrelet.

Aguirre-Muñoz, A.; Bedolla-Guzmán, Y.; Hernández-Montoya, J.; Latofski-Robles, M.; Luna-Mendoza, L.; Méndez-Sánchez, F.; Ortiz-Alcaraz, A.; Rojas-Mayoral, E.; Samaniego-Herrera, A. 2018. The conservation and restoration of the mexican islands, a successful comprehensive and collaborative approach relevant for global biodiversity. In: Ortega-Rubio, A. (ed.), Mexican Natural Resources Management and Biodiversity Conservation, pp. 177-192. Springer.

Bedolla Guzmán, Yuliana, Alfonso Hernández Ríos, Esmeralda Bravo Hernández and Alejandra Fabila Blanco. "Conservation status of Craveri's Murrelet in Mexico." Grupo de Ecología y Conservación de Islas, A.C. (2019)

BirdLife International. 2020. Synthliboramphus craveri. The IUCN Red List of Threatened Species2020: e.T22694887A179078444. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22694887A179078444.en. Downloaded on 07 February 2021.

BirdLife International. 2018. Synthliboramphus antiquus. The IUCN Red List of Threatened Species 2018: e.T22694896A132580015. https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22694896A132580015.en. Downloaded on 07 February 2021.

Breese, Dawn, et al. "Craveri's Murrelet: Confirmed Nesting and Fledging Age at San Pedro Martir Island, Gulf of California." Colonial Waterbirds, vol. 16, no. 1, 1993, p. 92. DOI.org (Crossref), doi:10.2307/1521562.

Brzezinski, Mark A., and Libe Washburn. "Phytoplankton primary productivity in the Santa Barbara Channel: Effects of wind-driven upwelling and mesoscale eddies." Journal of Geophysical Research: Oceans 116.C12 (2011).

Carter, Harry R., et al. "Biology and conservation of Xantus's Murrelet: discovery, taxonomy, and distribution." Marine Ornithology 33 (2005): 81-87.

"Craveri's Murrelet." Audubon, 30 Apr. 2020, www.audubon.org/field-guide/bird/craveris-murrelet.

Del Hoyo, Josep, et al. Handbook of the birds of the world. Vol. 1. No. 8. Barcelona: Lynx edicions, 1992.

DeWeese, Lawrence R., and DEWEESE LR. "Distribution and breeding biology of Craveri's Murrelet." (1976).

Everett, WILLIAM T., and DANIEL W. Anderson. "Status and conservation of the breeding seabirds on offshore Pacific islands of Baja California and the Gulf of California." Seabird status and conservation: a supplement, ICBP Technical Publication 11 (1991): 115-139.

Gaston, Anthony J., and Joanna L. Smith. "Changes in oceanographic conditions off northern British Columbia (1983 1999) and the reproduction of a marine bird, the Ancient Murrelet (Synthliboramphus antiquus)." Canadian Journal of Zoology 79.10 (2001): 1735-1742.

Grémillet, David, and Thierry Boulinier. "Spatial ecology and conservation of seabirds facing global climate change: a review." Marine Ecology Progress Series 391 (2009): 121-137.

Hyrenbach, K. David, and Richard R. Veit. "Ocean Warming and Seabird Communities of the Southern California Current System (1987–98): Response at Multiple Temporal Scales." Deep Sea Research Part II: Topical Studies in Oceanography, vol. 50, no. 14–16, Aug. 2003, pp. 2537–65. DOI.org (Crossref), doi:10.1016/S0967-0645(03)00123-1.

Karnovsky, Nina J., et al. AT-SEA DISTRIBUTION, ABUNDANCE AND HABITAT AFFINITIES OF XANTUS'S MURRELETS. 2005, p. 16.

NOAA. "What Years Are ENSO Years?" NOAA/ESRL Physical Sciences Laboratory, Boulder Colorado, n.d. psl.noaa.gov/enso/past_events.html (retrieved on March 30, 2021). Paleczny, M., Hammill, E., Karpouzi, V., & Pauly, D. (2015). Population trend of the world's monitored seabirds, 1950-2010. PloS one, 10(6), e0129342.

Piatt, John F., et al. "Extreme mortality and reproductive failure of common murres resulting from the northeast Pacific marine heatwave of 2014-2016." PLoS One 15.1 (2020): e0226087. Pinsky, Malin L., et al. "Climate-Driven Shifts in Marine Species Ranges: Scaling from Organisms to Communities." Annual Review of Marine Science, vol. 12, no. 1, Jan. 2020, pp. 153–79. DOI.org (Crossref), doi:10.1146/annurev-marine-010419-010916.

Pinsky, M. L., et al. "Marine Taxa Track Local Climate Velocities." Science, vol. 341, no. 6151, Sept. 2013, pp. 1239–42. DOI.org (Crossref), doi:10.1126/science.1239352.

Rasmussen, Linda L., et al. "A century of Southern California coastal ocean temperature measurements." Journal of Geophysical Research: Oceans 125.5 (2020): e2019JC015673.

Sanctuary Integrated Monitoring Network . "Upwelling on the Central California Coast." SIMoN, 17 July 2004, sanctuarysimon.org/2004/07/upwelling-on-the-central-california-coast/.

Speckman, Suzann G., et al. "Temporal Variability in Abundance of Marbled Murrelets at Sea in Southeast Alaska." Waterbirds: The International Journal of Waterbird Biology, vol. 23, no. 3, 2000, p. 364. DOI.org (Crossref), doi:10.2307/1522174.

Springer, Alan M., et al. "Status, ecology, and conservation of Synthliboramphus murrelets and auklets." Status and conservation of seabirds in the North Pacific. Canadian Wildlife Service, Ottawa (1993): 187-201.

Van Rossem, A. J. "The Craveri Murrelet in California." The Condor, vol. 28, no. 2, Mar. 1926, pp. 80–83. DOI.org (Crossref), doi:10.2307/1362927.

Veit, Richard R., Peter Pyle, and John A. McGowan. "Ocean warming and long-term change in pelagic bird abundance within the California current system." Marine Ecology Progress Series 139 (1996): 11-18.

Velarde, Enriqueta, et al. "Warm oceanographic anomalies and fishing pressure drive seabird nesting north." Science Advances 1.5 (2015): e1400210.

Velarde, Enriqueta, et al. THE STATUS OF CRAVERI'S MURRELET SYNTHLIBORAMPHUS CRAVERI AND REOCCUPATION OF A FORMER NESTING AREA. 2011, p. 5.

Vermeer, Kees, et al. "Differential Use of Zooplankton Prey by Ancient Murrelets and Cassin's Auklets in the Queen Charlotte Islands." Journal of Plankton Research, vol. 7, no. 4, 1985, pp. 443–59. DOI.org (Crossref), doi:10.1093/plankt/7.4.443.

Wingfield, J C et al. "A mechanistic approach to understanding range shifts in a changing world: What makes a pioneer?." General and comparative endocrinology vol. 222 (2015): 44-53. doi:10.1016/j.ygcen.2015.08.022

Wolter, Klaus. "Multivariate ENSO Index (MEI)." NOAA Earth System Research Laboratory - Physical Sciences Division. National Atmospheric and Oceanic Administration, n.d. https://psl.noaa.gov/enso/mei/data/meiv2.data. (retrieved on April 17, 2021).

Karina Halliman

TRELS Cohort: 2021

Biography:

I recently graduated from UCSD with a Bachelor of Science in Environmental Systems: Ecology, Behavior, and Evolution. During my undergraduate time, I was involved with Alternative Breaks and The Vagina Monologues & Their Stories. My interests include the intersections between environmental issues, social justice, and conservation. I want to pursue a Ph.D., but first I want to explore different aspects of scientific research to determine what exactly interests me.

> *"I am interested in learning about the process of publication....to show off the hard work I have put into my research in the past year, and to expose more people to marine ecology in an accessible manner."*

Acknowledgements:

This research was supported by the Tritons Research Experiential Learning Scholars (TRELS) program at UC San Diego. I gratefully thank my mentor Tammy Russell and my advisor Maria Vernet for their continued support. I would also like to thank my parents, my biggest cheerleaders, who instilled in me the resiliency and guidance needed for my journey in higher academia and beyond.