BLACK OYSTERCATCHER (HAEMATOPUS BACHMANI) POPULATION SIZE, USE OF MARINE RESERVE COMPLEXES, AND SPATIAL DISTRIBUTION IN OREGON

Authors: Liebezeit, Joe, O'Connor, Amelia, Lyons, James E, Shannon, Courtney, Stephensen, Shawn, et. al.

Source: Northwestern Naturalist, 101(1) : 14-26

Published By: Society for Northwestern Vertebrate Biology

URL: https://doi.org/10.1898/1051-1733-101.1.14

BLACK OYSTERCATCHER (*HAEMATOPUS BACHMANI*) POPULATION SIZE, USE OF MARINE RESERVE COMPLEXES, AND SPATIAL DISTRIBUTION IN OREGON

JOE LIEBEZEIT
Portland Audubon, 5151 NW Cornell Rd, Portland, OR 97210 USA; jliebezeit@audubonportland.org

AMELIA O'CONNOR
6330 Nellie Ave, Otter Rock, OR 97369 USA

JAMES E LYONS
U.S. Geological Survey Patuxent Wildlife Research Center, 12100 Beech Forest Rd, Laurel, MD 20708 USA

COURTNEY SHANNON
Portland Audubon, 5151 NW Cornell Rd, Portland, OR 97210 USA

SHAWN STEPHENSEN
Oregon Coast National Wildlife Refuge Complex, US Fish and Wildlife Service, 2127 SE Marine Science Drive, Newport, OR 97365 USA

ELISE ELLIOTT-SMITH
U.S. Geological Survey Forest and Rangeland Ecosystem Science Center, 3200 SW Jefferson Way, Corvallis, OR 97331 USA

ABSTRACT—The Black Oystercatcher is a large shorebird found along the west coast of North America. Because of its small global population size, low reproductive rate, and dependence on rocky intertidal habitats, it is considered a "species of high conservation concern" and may act as an indicator of intertidal ecosystem health. In 2015, Portland Audubon initiated a 3-y shore-based population survey in Oregon building upon long-term monitoring previously conducted by the US Geological Survey (USGS) and others. The objectives were to: (1) estimate the current minimum population of breeding Black Oystercatchers in Oregon and compare to previous estimates; (2) document oystercatcher abundance on shoreline adjacent to the Oregon's system of Marine Reserves (MRs) and Marine Protected Areas (MPAs); and (3) describe the spatial distribution of breeding oystercatchers along the coast. We targeted all rocky shoreline along Oregon's coastline to conduct abundance surveys each spring from 2015–2017. A total of 75 survey routes were sampled using a standardized land-based survey protocol. Trained volunteer community scientists conducted the majority of the surveys. We used *N*-mixture statistical models to estimate oystercatcher population size and probability of detection. Population estimates from the best-fitting models were consistent, with estimates ranging from 506 oystercatchers in 2016 (95% credible interval, 463–560) to 629 (548–743) in 2015. These estimates described a small but stable population. Probability of detection remained consistent across years (ranging from 0.51 to 0.53). Breeding density of oystercatchers was higher in southern Oregon. Oystercatcher abundance adjacent to MRs-MPAs accounted for between 12.4–18.3% of the total population estimate, which was lower than expected (approximately 25%). Subsequent conservation efforts for Black Oystercatchers in Oregon could be successful by focusing on limiting human disturbance, particularly on the north and central coasts, and protecting core habitats on the south coast where much of the population resides.

Key words: Black Oystercatcher, *Haematopus bachmani*, Marine Protected Areas, Marine Reserves, *N*-mixture modeling, Oregon, population size, spatial distribution

The Black Oystercatcher (*Haematopus bachmani*) is a relatively large (500–700 g) and conspicuous shorebird found along the west coast of North America, ranging from the Aleutian Islands down to Baja California (Andres and Falxa 1995). This species is considered an intertidal obligate and depends on marine shoreline habitats year-round. In Oregon, it is particularly dependent on near-shore rocks and islands, rocky shorelines, and headlands for foraging and nesting. Oystercatchers forage exclusively on intertidal macroinvertebrates, primarily bivalves and other mollusks (such as limpets, whelks, and mussels) (Jehl 1985). In the southern portion of their range (Washington, Oregon, and California), Black Oystercatchers are believed to be year-round residents and make only short distance movements in winter for flock formation, remaining relatively close to breeding areas (Hartwick and Blaylock 1979; Falxa 1992). In southern Alaska and British Columbia, Black Oystercatchers often make medium to long-distance (>200 km) migrations after the breeding season (Johnson and others 2010).

Because of their small global population size (estimated between 8,900 and 11,000) (Andres and Falxa 1995; Tessler and others 2014), and relatively small breeding and nonbreeding distributions, the Black Oystercatcher is considered a "species of high concern" by the US and Canadian National Shorebird Conservation Plans (US Shorebird Conservation Plan Partnership 2016; Donaldson and others 2000). It is also a focal species in the Pacific Americas Shorebird Conservation Strategy (Senner and others 2016), and is on the watch list in the most recent State of North America's Birds report (NABCI 2016). In Oregon, the Black Oystercatcher was recently listed by the Department of Fish and Wildlife as a "strategy species" (i.e., species in need of greatest management attention) in the Oregon Nearshore Strategy (ODFW 2016). Because Black Oystercatchers are dependent on intertidal areas, they are particularly vulnerable to habitat degradation, oil spills, sea-level rise, and possibly ocean acidification associated with a changing climate (Tessler and others 2007, Hollenbeck and others 2014). They are also susceptible to human disturbance, particularly during the nesting season (Morse and others 2006; Andres and Falxa 1995).

In 2012, 5 Marine Reserves (MRs) and Marine Protected Areas (MPAs) were designated in Oregon's nearshore waters (shoreline to 3 nautical miles; Fig. 1), with fisheries harvest restrictions incrementally going into effect 2012–2016. In MRs, all removal of marine life is prohibited, as is ocean development and infrastructure. In MPAs, ocean development is prohibited, but some fishing activities are allowed. MRs-MPAs were established to conserve marine habitats and biodiversity and facilitate scientific research. The Black Oystercatcher, as a top trophic-level predator and rocky intertidal zone obligate species, helps to structure rocky intertidal ecosystems (Wootton 1992; Lindberg and others 1998) and, thus oystercatcher population persistence may act as an indicator of overall health in the intertidal ecosystem. Therefore, monitoring oystercatcher use of rocky intertidal habitat adjacent to MRs-MPAs may lend some perspective into how effectively the adjacent reserves support intertidally dependent species like the Black Oystercatcher.

In Oregon, the most recent estimate of the Black Oystercatcher population, resulting from land-based surveys in 2006, is approximately 300 birds (Lyons and others 2012). In 2015, Portland Audubon re-initiated an intensive coast-wide, shore-based survey in Oregon and conducted these surveys for 3 consecutive seasons (2015–2017). The main objectives of this study were to: (1) estimate the current minimum population of breeding Black Oystercatchers in Oregon and compare that to previous estimates; (2) document oystercatcher abundance in rocky shoreline habitat adjacent to the Oregon's newly established system of MRs-MPAs; and (3) describe the spatial distribution of oystercatchers along the coast during the breeding season.

METHODS

Abundance Surveys

We targeted all rocky shoreline habitats along Oregon's coastline to conduct abundance sur-

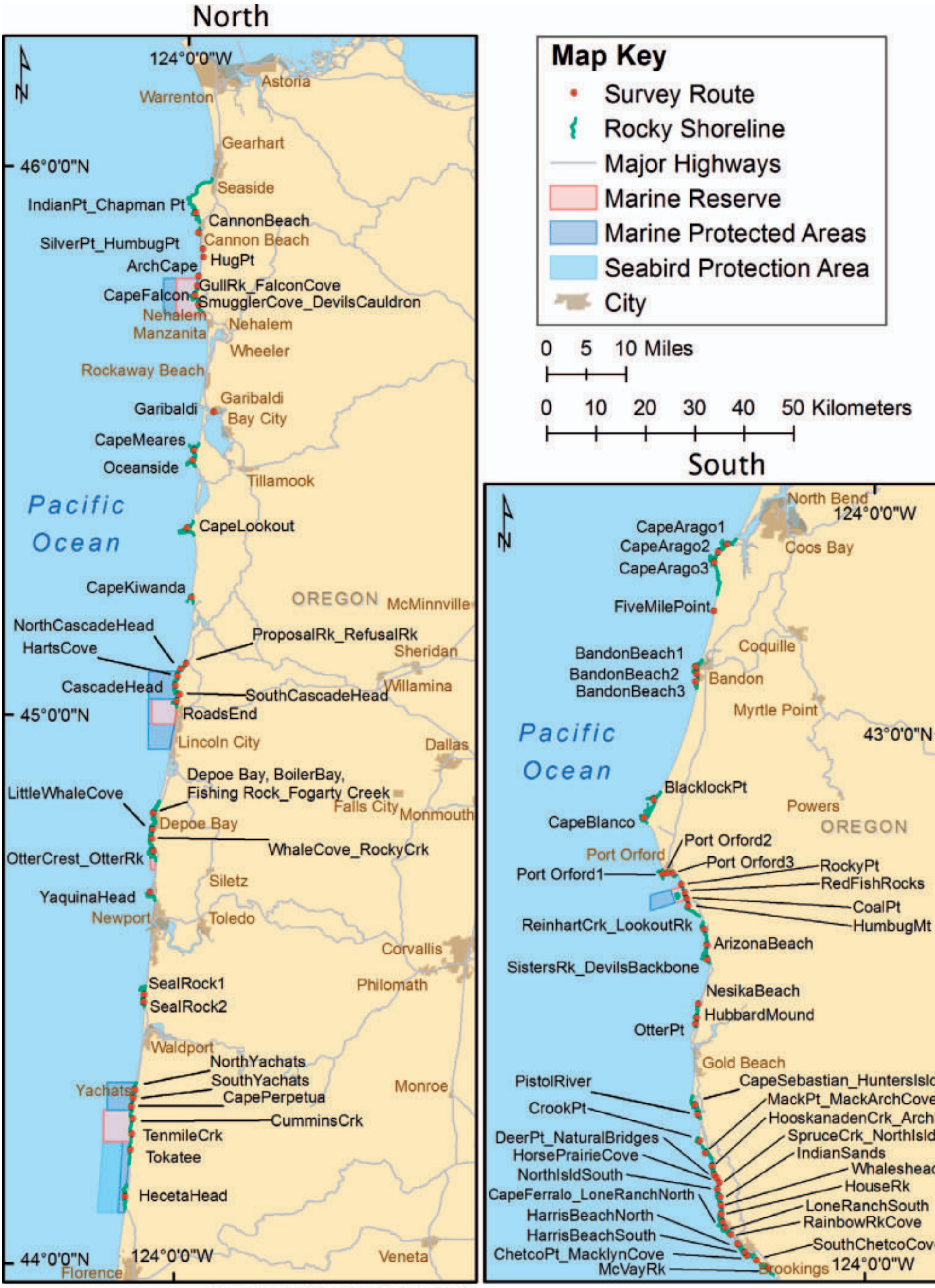

FIGURE 1. Locations and names of survey routes where Black Oystercatcher abundance surveys were performed in 2015–2017. Each survey route is depicted as the transect centroid. In 2015, some of these routes were combined.

veys. Sandy beaches and jetties were not surveyed because oystercatchers do not use these habitats for nesting. As in the previous survey (Lyons and others 2012), off-shore islands that were too far from shore to be reliably viewed with optics were not surveyed ($\sim$ 0.75 km). To conduct the abundance surveys, observers were assigned 1 or more survey routes along the rocky intertidal coastline, which were accessed on foot and by vehicle. A total of 60 survey routes were established in 2015 and 75 survey routes were established in 2016 and 2017 (Fig. 1), based on routes previously used in earlier abundance surveys (Elliott-Smith and Haig 2006; Lyons and others 2012). The increase in survey routes in 2016 and 2017 was due to 9 existing routes being split into 21 smaller routes for logistical purposes. In addition, 3 new routes were added. These routes included all known accessible mainland rocky intertidal habitat and near-shore islands, but did not include a small number of distant offshore islands that could only be surveyed by boat.

We used an existing protocol developed by the US Geological Survey (USGS) to conduct Black Oystercatcher abundance surveys (Elliott-Smith and Haig 2006). Two or more abundance surveys were made between 3 May and 3 June in all years, to allow detectability estimation. We attempted to conduct surveys with at least 5 d between replicates. The timing of abundance surveys corresponds with peak mating pair establishment and courting behavior during the early breeding season when oystercatchers are most conspicuous.

During a typical survey, trained observers used binoculars and/or spotting scopes, and stopped at 1 or more arbitrarily chosen observation points for a minimum of 10 min per observation point along the survey route to find and count oystercatchers. Oystercatchers were typically detected visually, but we also counted birds detected by ear. Surveys in each route were conducted for a minimum of 30 min, and up to $\geq$2 h for longer routes. All detected birds were plotted on a map and recorded on a data form. Observers recorded behaviors and visual clues to help determine whether birds were likely breeding pairs or unpaired sub-adults. Surveys were typically conducted in the morning to maximize best possible light for viewing, and periods of inclement weather were avoided. Attempts were made to avoid double counting, such as keeping track of individuals identified along the survey route and monitoring their movements. Surveys that did not follow protocol instructions were excluded from the analysis.

Population Estimate Analysis

We used the *N*-mixture model to estimate both minimum oystercatcher population size and probability of detection (Royle 2004; Lyons and others 2012). This method provides a flexible framework for modeling count data because it allows incorporation of additional explanatory variables (covariates) to refine the estimate. This same statistical procedure was previously used to provide the most recent (2006) Oregon oystercatcher population estimate (Lyons and others 2012), and was appropriate for using with the current dataset because it was collected using the same methods. We included route length and observation points per route (proxies for survey route size), and section of coast (north vs. south coast[1]; north, central, south[2]) as covariates in the population estimate. We also considered including rain, wind speed, and number of observers as covariates in the analysis. However, in the 2006 study (Lyons and others 2012), among all 3 covariates, only rain was important in affecting detection probability. None of the surveys from 2015–2017 were conducted in rain or wind conditions that affected observer visibility or survey performance, so we did not include rain, wind speed, or number of observers as covariates in the analysis. We used this modeling approach to calculate an overall coast-wide oystercatcher population estimate and an abundance estimate for oystercatchers using habitat adjacent to Oregon's 5 MRs-MPAs. We fit the *N*-mixture model in a Bayesian analysis using WinBUGS software (Spiegelhalter and others 2003). We used noninformative priors for all parameters and ran 3 Markov chain Monte Carlo (MCMC) simulations. Each Markov chain contained 50,000 iterations; we discarded the first 25,000 as "burn-in" to reduce the effect of the initial parameter values in each chain (Gelman et al.

[1] We designated Oregon Dunes National Recreation Area as separating north and south coast regions.
[2] North coast = Columbia River to Neskowin; Central coast = Neskowin to Florence; South coast = Florence to California border.

TABLE 1. A comparison of Oregon oystercatcher surveys in 2006 and 2015–2017.

Metric	2006	2015	2016	2017
Number of routes	56	60	74	75
Mean number of visits per route	1.8	1.6	2.5	2.5
Population index (sum of highest count per route)	252	374	367	420
Estimated minimum population size (*N*-mixture model)	311*	629	506	580
Lower 95% Credible Interval	276	548	463	534
Upper 95% Credible Interval	382	743	560	638
Probability of detection (*N*-mixture model)	0.68*	0.53	0.51	0.52

* The 2006 estimate used a mixture model with lognormal errors to account for over-dispersion in (Poisson) abundance and extra-binomial variation in detection (Lyons and others 2012); in 2015–2017 we used a negative binomial (abundance) and binomial (detection) mixture model.

2004). Chain convergence on posterior distributions was monitored with the $\bar{R}$ statistic (Gelman and Hill 2007), and model fit was evaluated using posterior predictive checks. We summarized posterior distributions of abundance and detection parameters using medians and 95% Bayesian credible intervals (CRI). We followed procedures described in Lyons and others (2012) for extrapolating the population estimate to the unsampled survey routes. There were 3 unsampled sites in 2015, and 1 unsampled site in 2016; we added these sites to the data file (with missing data for the counts at these sites), and population sizes were estimated for these sites at each iteration of the MCMC algorithm. Competing population models were compared using Deviance Information Criterion (DIC) model selection (Spiegelhalter and others 2002).

Oystercatcher Spatial Distribution

Although geographic regions were included in the *N*-mixture model to help explain variation in counts, we also qualitatively compared oystercatcher spatial distribution across the coast by comparing the population estimates per geographic region and average number of oystercatchers observed per site while also providing effort description for these comparisons (route length, number of observation points, and number of repeated visits). We used ArcGIS (ESRI 2016) to graphically display survey-route abundance categories based on average birds detected across survey replicates.

Results

Effort

Each year, route surveys were conducted by more than 60 observers consisting of trained volunteers and agency and Portland Audubon biologists. Across the 3 study seasons, $\geq$95% of all established routes were surveyed for Black Oystercatcher abundance (Fig. 1). The number of repeated abundance surveys conducted annually per site ranged from 1 to 6. For the *N*-mixture model population estimates, analysis was limited to the first 3 visits because there were few sites with more than 3 visits. Average individual route surveys (number of visits) included in the analyses were 1.6 in 2015 and 2.5 in both 2016 and 2017 (Table 1).

Coast-wide Population Estimates

The best-fitting *N*-mixture models for total population size across the 3 y of this study were consistent with estimates ranging from 506 in 2016 to 629 in 2015 (Table 1). Evidence of a statistically significant difference in these estimates is not supported because there is overlap in the CRIs for all 3 y. However, the 2016 and 2015 estimates barely overlap, suggesting a near-significant difference in the population estimate for those years. Both the 2016 and 2017 estimates are more precise compared to the 2015 estimate (narrower CRIs), which is likely due to the increase in survey replicates per route in 2016 and 2017. In 2015–2017, a negative binomial/binomial mixture provided a better model fit, whereas in 2006, a Poisson/binomial mixture with log/logit normal errors was used (Lyons and others 2012). The probability of detection was lower than in 2006 but remained consistent (ranging from 0.51 to 0.53) from 2015 to 2017 (Table 1).

In 2015, the model with most support was the null model, whereas in 2016 and 2017 the top models include number of observation points (Table 2). There was a positive relationship, with each additional observation point adding about 1 bird (in 2016 in the north) and 1.1 birds (in 2017). The top 2016 model also included

TABLE 2. Top 3 *N*-mixture models per year for coast-wide Black Oystercatcher minimum population estimate. DIC is Deviance Information Criterion and pD is a measure of model complexity.

Description	pD	DIC	*N*	95% Confidence Interval Lower (*N*)	95% Confidence Interval Upper (*N*)	*p*	95% Confidence Interval Lower (*p*)	95% Confidence Interval Upper (*p*)
Year: 2015								
Model 1: Null *N*(.), *p*(i,t)	136	418	629	548	743	0.53	0.48	0.58
Model 2: # obs. Points	138	422	636	551	761	0.53	0.48	0.58
Model 3: # obs. points + North-South zones*	–	–	–	–	–	–	–	–
Year: 2016								
Model 1: *N*(# obs. points + North/South zones), *p*(i,t)	223	689	506	463	560	0.51	0.48	0.55
Model 2: *N*(# obs. points), *p*(i,t)	225	692	508	465	563	0.51	0.48	0.55
Model 3: Null *N*(.), *p*(i,t)	227	694	508	466	563	0.51	0.48	0.55
Year: 2017								
Model 1: *N*(# obs. points), *p*(i,t)	246	761	580	534	638	0.52	0.49	0.55
Model 2: Null *N*(.), *p*(i,t)	248	777	597	551	653	0.50	0.47	0.54
Model 3: *N*(# obs. points + North-South zones), *p*(i,t)*	–	–	–	–	–	–	–	–

* Estimates not available (convergence failure)

geographic region (north-south split) as a predictor of abundance (Table 2). The effect of geographic region in 2016 corresponded with higher bird density in the southern region; on average, there were about 2 more birds per route in the south. Population size (and probability of detection) was very similar for all top models that were fit in each year (Table 2). Overall, the coast-wide population estimates for both 2015 and 2016 are larger than the 2006 estimate (Table 1), evidence that the oystercatcher population on the Oregon coast does not appear to be declining and may have increased in recent years.

Marine Reserve Protected Area Population Estimate

The best *N*-mixture model oystercatcher population estimate for survey routes adjacent to Oregon's 5 MRs-MPAs ranged from approximately 50 to 100 birds (Table 3). Estimates increased over the 3 y, likely concomitant with increased effort at the sites (number of routes sampled per year). According to the models, Black Oystercatcher abundance adjacent to MRs-MPAs accounted for approximately 12.4% of the total population estimate in 2015, 13.2% in 2016, and 18.3% in 2017.

TABLE 3. Estimated population size (number of birds) from survey routes adjacent to Oregon's 5 marine reserve/marine protected area complexes. Estimates and credible interval are from an *N*-mixture model.

Metric	2015	2016	2017
Number survey route replications	13	17	19
Estimated minimum population size[1]	48	67	106
95 % Credible Interval:			
Lower	34	52	88
Upper	95	91	130

[1] Number of birds in Oregon MRs and MPAs

Comparison of Oystercatcher Abundances between Geographic Regions

Both the *N*-mixture model population estimates and average oystercatchers counted per route for the north versus south regions show that the south region supports substantially more of the oystercatcher population compared to the north coast (between 62 and 67% more in the south in a given year) (Table 4, Fig. 2). In 2016, only this covariate was included in the best *N*-mixture model as an important predictor of abundance. Level of effort, including sample size (number of repeated survey visits), average route lengths, and average number of observation points was higher in the south region (Table 4). This increased effort was marginal in most cases, but still may explain some of the higher numbers on the south coast and must be taken into account when evaluating this comparison.

DISCUSSION

This study provides the 1st minimum population estimate of breeding Black Oystercatchers

TABLE 4. Estimated Black Oystercatcher population size (number of birds), average birds per route, and effort characteristics (survey sample size, route length, and number of observation points) in the north and south geographic regions of the Oregon coast.

Year	Sample size for avg. counts*		*N*-mixture population estimate**		Average birds counted / route (± SD)		Avg. route length (m) (± SD)		Avg. number of observation points / route (± SD)	
	North	South	North	South	North	South	North	South	North	South
2015	44	54	226 (171–303)	399 (351–474)	3.09 ± 3.6	8.2 ± 5.9	2193.3 ± 1422.2	2198.7 ± 1707.0	4.6 ± 3.7	5.9 ± 4.1
2016	85	107	168 (146–201)	336 (302–385)	2.94 ± 3.7	4.1 ± 3.6	3313.0 ± 2000.2	3108.7 ± 1816.9	4.3 ± 2.8	4.3 ± 2.9
2017	98	102	220 (192–255)	360 (329–399)	3.07 ± 2.8	5.0 ± 3.7	2481.9 ± 1630.0	3180.0 ± 1771.0	3.4 ± 2.1	4.2 ± 2.0

* Number of repeated visits (survey days)
** From best *N*-mixture model; includes 95% Credible Interval

in Oregon since 2006. We suggest, based on the evidence, that the population is small but currently stable and may have increased over the last decade. Although survey methods and route coverage extent were replicated from the 2006 estimate, direct comparison of the 2006 (Lyons and others 2012) and 2015–2017 *N*-mixture model population estimates is confounded by the different model assumptions of the best-fitting model (2015–2017: negative binomial/binomial mixture versus 2006: Poisson/binomial mixture with log/logit normal errors). However, the 2015–2017 raw data alone corroborate support for a population increase because at most comparable survey routes (between 2006 and 2015–2017) maximum counts were higher in 2015–2017 (Table 1). Before 2006, there had been no rigorous population estimates of Black Oystercatchers in Oregon. The US Fish and Wildlife Service (USFWS) has opportunistically monitored Black Oystercatchers during their annual seabird colony surveys (which included offshore rocks) conducted since 1988, and organized occasional incomplete surveys on the central and north coasts of Oregon before 2006. Although USFWS estimates are rough, their 2007 estimate was 470 oystercatchers (Naughton and others 2007) and their most recent estimate is 521 oystercatchers (USFWS 2019). The more recent estimate is based largely on data collected in 2015–2017, and contains a combination of data collected as part of this study as well as data collected independently by USFWS. In any case, the comparison between the 2 USFWS estimates provides additional evidence of stable or small increase in the population as we report in this study.

Analysis of the Christmas Bird Count (CBC) data from 1966–2017 and over the shorter term (2007–2017) shows no change in Black Oystercatcher numbers in Oregon. The mean average annual rate of change in the CBC population index was –0.55 from 1966–2017 (2007–2017: –0.39) with a 95% credible interval of (1966–2017: –1.88, 0.82; 2007–2017: –3.09, 3.52) (Meehan and others 2017); because the credible interval includes zero, these trends are not significant. This estimate is based on an average of 5.2 CBC circles (24.1 km diameter) sampled per year on the entire Oregon coast during the 52-y period covered by the analysis (Timothy Meehan, National Audubon Society, Boulder, CO, pers. comm., 2018). There is currently little informa-

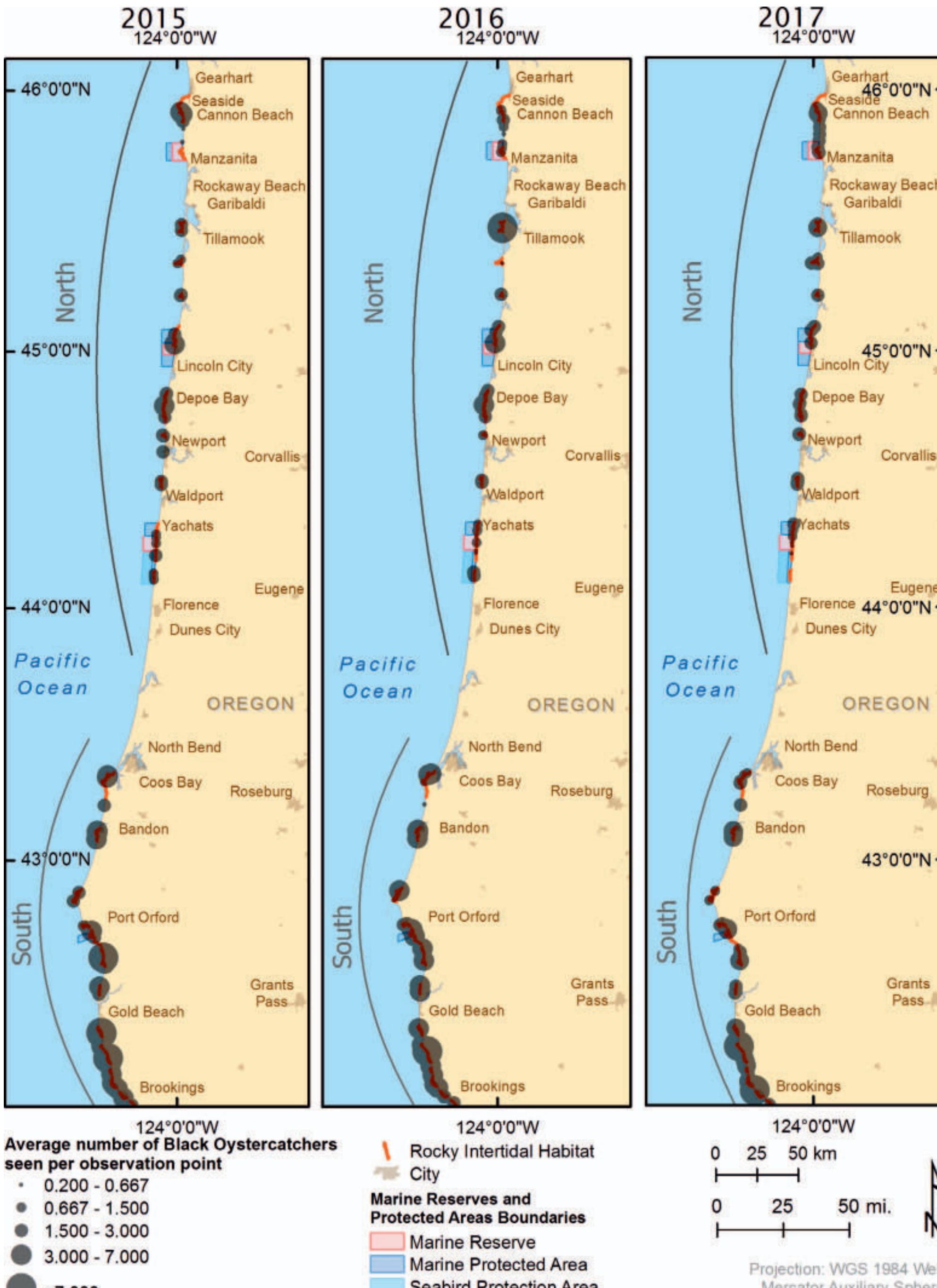

FIGURE 2. Distribution of Black Oystercatcher abundance along the Oregon coast, 2015, 2016, and 2017. Black dots represent the average number of oystercatchers seen per observation point.

tion on oystercatcher movement in the southern portion of their breeding range (south of British Columbia), although some authors suggest a sedentary population (Hartwick and Blaylock 1979; Falxa 1992), whereas in winter they are more often observed in communal groups (Andres and Falxa 1995). Consequently, a more clumped distribution in winter could lead to greater error in estimates if survey coverage is not comprehensive. Hartwick and Blaylock (1979) found that at a site in British Columbia a significant number of wintering oystercatchers flew to mudflats to forage during the daytime and back to the coast at night. In Oregon, such wintering behavior has not been documented, although it could occur. Because the CBC analysis described above is based on a small subset of data along the Oregon coast, collected in the winter when the birds are likely unevenly distributed and more difficult to detect, and because the trend estimate is not significant, our confidence of a potential negative population trend based on CBC data is low.

There are multiple important assumptions related to our population estimate that we may not have met. Because some survey routes had incomplete coverage, the assumption of homogeneity of detection was likely not entirely met. Although our coverage included survey routes targeting all rocky shoreline suitable for breeding oystercatchers, some survey routes had poor coverage because the areas were difficult to access. Also, there were inevitable differences in observer ability to access routes depending on the terrain and property ownership. For some routes, observers were able to walk along a transect and traverse habitat, whereas in other areas surveys could only be performed from observation points where habitat was scanned from a distance and the view was incomplete. We do not expect substantial bias in our estimates, however, because coverage on most sites was adequate and consistent, and simulation studies suggest that individual heterogeneity may not bias abundance estimates from the *N*-mixture model (Kéry and Royle 2016: Chapter 6).

Double counting individual oystercatchers is a potential source of bias in this study. Our protocol and training emphasize the need to avoid double counting. At large sites that take a long time to survey, however, the assumption may be violated. In years 2 and 3 of this study, we split larger survey routes into more manageably sized ones for logistical reasons, and thus may have minimized double counting as a source of bias when surveys were conducted on the same day and time period. Movements of subadults are another potential source of double-counting bias (Lyons and others 2012). Because we were not confident in identification of nonbreeding subadults, we analyzed all oystercatchers without distinguishing breeding status. Subadult oystercatchers generally do not defend territories, and they may wander (move among multiple sites) more than adults. If subadults regularly use >1 of the survey routes, individual birds could be double counted and our population size estimates would be biased high (Lyons and others 2012). Subadults often associate in small groups, and this behavior could also lead to a violation of the assumption of independence of detections among individuals. Paired adults could also violate this assumption. Implications of a violation of this assumption are not clear, but it could result in an estimate of detection probability that is biased high, and therefore an estimate of abundance that is biased low. We occasionally did observe small flocks (likely subadult birds) during survey visits, but these observations were infrequent. Studies using individually marked birds and telemetry in our study area would allow a better understanding of local movements as a source of bias (Lyons and others 2012). Finally, because we restricted our survey period to a relatively narrow window of time (approximately 3 wk), we assumed there was no significant oystercatcher movement into and out of sites during the survey period.

We assumed oystercatchers were not using sandy beach habitats during the breeding season. This assumption is likely not a significant source of bias in the population estimate because in the southern part of this species' range they are closely tied to rocky shoreline and intertidal habitats, especially during the breeding season. Although we did relegate sampling to rocky shoreline habitat, this often included intermittent stretches of sandy beach habitat among rocky shoreline dominated habitat. However, we did not sample large stretches of sandy habitat (such as Oregon Dunes National Recreation Area), and it is possible that we missed some birds in these areas.

Weinstein and others (2014) documented oystercatchers on sand and gravel beaches during the breeding season, but these were typically in close proximity or within a matrix of rocky shoreline habitats (Anna Weinstein, Audubon California, San Francisco, CA, pers. comm., 2018). We did not conduct systematic surveys of the small number of distant off-shore islands that can only be reliably sampled by boat. Over the 3 y of this project, observers did conduct 4 opportunistic boat surveys of off-shore islands, both in Marine Reserves, during the sampling period (2 surveys at Gull and Otter Rocks and 2 at Redfish Rocks). Only 1 oystercatcher was observed at Redfish Rocks and 5 on Gull and Otter Rocks. These surveys were not included in the population estimate. Future oystercatcher population estimate surveys in Oregon should attempt to systematically sample offshore islands if feasible.

Variability in observer experience conducting surveys may also have affected the population estimates. However, we provided multiple trainings each year attended by many of the volunteers prior to surveys. Most observers conducted surveys during multiple years of the project and some had previously helped conduct surveys during the USGS-led effort in 2006. Black Oystercatchers are easy to identify, even for inexperienced volunteers, and they are quite conspicuous in May during the early breeding period, making them ideal for community science (also known as "citizen science"). Other researchers have relied on community scientists for Black Oystercatcher population monitoring and for developing published population estimates (Lyons and others 2012; Weinstein and others 2014).

We found that the south coast of Oregon (defined as south of 43°N) appears to support a higher number of oystercatchers compared to the central and north coast, and that the average number of birds per survey route is higher on the south coast. Our annual surveys from 2015–2017 consistently estimate that the south coast Black Oystercatcher population makes up for over 60% of the total breeding population (Table 4). The USFWS estimate of oystercatchers in Oregon also shows the south coast with a significant portion of the Black Oystercatcher population (46%) (Naughton and others 2007). In terms of linear distance, the south coast contains more rocky shoreline habitat than both the north and central coasts combined (136.9 km vs. 121.5 km; south coast = 53%) (ODFW 2005); and therefore, part of the higher abundance on the south coast may be explained by the greater availability of suitable habitat. Also, our survey effort on the south coast was slightly higher than at sites on the north and central coast, and could have resulted in more birds being counted on the south coast. Despite this, inherent geomorphic features on the south coast, as well as differing physical and climatic factors may also be related to the apparent greater oystercatcher use of this region. Oregon's south coast is influenced by geologic processes associated with the Klamath-Siskiyou Ecoregion (ODFW 2016), resulting in greater rocky shoreline complexity compared to the rest of the Oregon coast. Black Oystercatcher nest survivorship data collected during the timeframe of this study (J Liebezeit, unpubl. data) and previously (E Elliott-Smith, unpubl. data) suggests that nearshore island nests have higher fledgling success than mainland nests. Most of the island nests, which were discovered opportunistically, were on the south coast, so there may be greater availability of higher quality island nesting sites on the south coast. Weinstein and others (2014) suggested that the California and southern Oregon's coast are unique in the Black Oystercatcher range, in terms of marine terrace and sea-stack geomorphology, enabling Black Oystercatchers to nest higher up above the high-tide line compared to other parts of their range. Such features may provide refugia for this species from the effects of climate change including sea-level rise and increasing storm frequency.

Human disturbance (and associated disturbance by pet dogs) is a factor influencing oystercatcher abundance patterns in the coastal regions. Because of the proximity to Willamette Valley cities, visitation rates to the north and central coast are higher than on the south coast, particularly during the summer tourist season (Epperly and others 2017), which overlaps the oystercatcher breeding season. We found that nests on the north coast were more likely to be disturbed by people/dogs than south and central coast nests. We also found that the incidence of both oystercatcher adults leaving their nests owing to human-related disturbance was much lower at south coast nests compared to both central and north coast nests (J Liebezeit, unpubl. data).

We would have expected more oystercatchers using rocky shoreline habitat in/adjacent to MRs-MPAs based on availability of suitable habitat. MRs-MPAs contain approximately 25% of the available rocky intertidal habitat in Oregon, yet in our population estimate, these areas supported <18%, approximately, of the oystercatcher population. However, although we were able to sample all MRs-MPAs, coverage was incomplete on some of them (for example, the northern portion of the Cape Falcon MR-MPA included difficult-to-access sites). Survey effort at MRs-MPAs increased each year during the survey, and in each year the MR-MPA population estimate increased, evidence that more complete coverage of the sites resulted in more birds detected.

In conclusion, Oregon has a small but apparently stable population of breeding Black Oystercatchers, and the south coast harbors the highest concentration of breeding birds in the state. The updated population estimate will help refine the range-wide population estimate, which is critical for effective conservation planning (Tessler and others 2014). Results of this effort are also contributing to a revision of the state-wide management plan for coastal rocky habitat (DLCD 2009). This project illustrates the powerful utility of community science in providing high quality data that inform management and conservation.

Future research that would inform better management and conservation of this species in Oregon could include an assessment of reproductive survivorship, particularly with respect to human disturbance and geomorphology, oystercatcher movement (via color-banding or with remote tracking devices), and assessment of wintering ecology and distribution patterns. Subsequent conservation efforts for Black Oystercatchers in Oregon that include efforts to limit human disturbance, particularly on the north and central coasts, and efforts to protect core habitats on the south coast where much of the population resides could be successful. To ensure best protection of oystercatcher foraging and nesting grounds in existing MRs-MPAs, habitat protections in rocky shoreline habitat adjacent to the MRs-MPAs that conform with existing MR-MPA protections could be implemented.

Acknowledgements

We thank the 83 volunteers that participated in this project. Without the hard work and dedication of this team of volunteers, this effort would have been impossible. In particular, we thank long-term volunteers: D and D Bilderback, J Evens, L Fink, D Franzini, K Hall, J Hurt, J Jones, E Kolkemo, G Maschmeyer, B Miller, B Minn, M Mueller, M Peters, L Quay, F Recht, D Villaescusa, and N Wagner for their dedication and extra efforts. We also thank the survey support of USFWS (V Loverti, A Melendez, J Nelson, M Robell, and D Wood), Oregon Department of Wildlife (P Atwood, H Biederback, J Kirchner, S Love, and D Nuzum), and the US Forest Service (M Dragoo, C Hase, A Morales-Santos, and J Oertley). We thank anonymous reviewers and Brad Andres for their help improving the manuscript. Funding support was provided by the David and Lucille Packard Foundation, the Harder Foundation, Friends of Cape Falcon, Haystack Rock Awareness Program, and Friends of Haystack Rock. We thank in-kind support of the USFWS, US Geological Survey, Kalmiopsis Audubon Society, Cape Arago Audubon Society, and Audubon Society of Lincoln City. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US Government.

Literature Cited

Andres BA, Falxa GA. 1995. Black Oystercatcher (*Haematopus bachmani*). In: Poole A, Gill F, editors. The birds of North America, No. 155. Philadelphia, PA: The Academy of Natural Sciences; Washington, DC: The American Ornithologists' Union.

[DLCD] Oregon Department of Land Conservation and Development. 2009. The Oregon territorial sea plan. Chapter 3. Rocky Shores Management Strategy. Salem, OR. Available from https://www.oregonocean.info/index.php/ocean-documents/planning/territorial-sea-plan2?limit=20&limitstart=20. Accessed 12 December 2018.

Donaldson GM, Hyslop C, Morrison RIG, Dickson HL, Davidson I. 2000. Canadian Shorebird Conservation Plan. Canadian Wildlife Service. Ottawa, Canada. 34 p. Available from: https://waterbirds.org/wp-content/uploads/CW69-15-5-2000-eng.pdf.

*Elliott-Smith E, Haig S. 2006. Standardized protocols for monitoring population size and reproductive success in the Black Oystercatcher, *Haematopus bachmani*. Corvallis, OR: US Geological Survey. 15 p.

*Epperly H, Swearingen T, Dalaba J. 2017. 2016 Visitor Intercept Survey: Coastal visitor ocean awareness.

* Unpublished.

Oregon Department of Fish and Wildlife, Marine Resources Program, Newport, OR. Unpublished report, 58 p.

ESRI 2016. ArcGIS Desktop: Release 10.4.1. Redlands, CA: Environmental Systems Research Institute.

FALXA G. 1992. Prey choice and habitat use by foraging Black Oystercatchers: Interactions between prey quality, habitat availability, and age of bird [dissertation]. Davis, CA: University of California. 195 p.

GELMAN, A., J. B. CARLIN, H. S. STERN, AND D. B. RUBIN. 2014. Bayesian data analysis. Second edition. Boca Raton, FL: CRC Press.

GELMAN A, HILL J. 2007. Data analysis using regression and multilevel/hierarchical models. New York, NY: Cambridge University Press. 625 p.

HARTWICK EB, BLAYLOCK W. 1979. Winter ecology of a Black Oystercatcher population. Studies in Avian Biology 2:207–215.

HOLLENBECK JP, OLSEN MJ, HAIG S. 2014. Using terrestrial laser scanning to support ecological research in the rocky intertidal zone. Journal of Coastal Conservation DOI 10.1007/s11852-014-0346-8.

JEHL JR. 1985. Hybridization and evolution of oystercatchers on the Pacific Coast of Baja California. Ornithological Monographs 36:484–504.

JOHNSON M, CLARKSON P, GOLDSTEIN MI, HAIG SM, LANCTOT RB, TESSLER DF, ZWIEFELHOFER D. 2010. Seasonal movements, winter range use, and migratory connectivity of the Black Oystercatcher. The Condor 112:731–746.

KÉRY M, ROYLE JA. 2016. Applied hierarchical modeling in ecology: Analysis of distribution, abundance and species richness in R and BUGS. Boston, MA: Elsevier. 783 p.

LINDBERG DR, ESTES JA, WARHEIT, KI. 1998. Human influences on trophic cascades along rocky shores. Ecological Applications 8:80–89.

LYONS JE, ROYLE JA, THOMAS SM, ELLIOTT-SMITH E, EVENSON JR, KELLY EG, MILNER RL, NYSEWANDER DR, ANDRES BA. 2012. Large-scale monitoring of shorebird populations using count data and *N*-mixture models: Black Oystercatcher (*Haematopus bachmani*) surveys by land and sea. The Auk 129:645–652.

MEEHAN TD, LEBARON GS, DALE K, MICHEL NL, SOYKAN CU, SAUER J, SCHUETZ JG, LANGHAM GM. 2017. Population trends for North American winter birds, from Audubon Christmas Bird Counts, 1966–2017, version 2.0. 2017. San Francisco, CA: National Audubon Society, San Francisco, CA. Available from: https://www.audubon.org/ conservation/where-have-all-birds-gone, Accessed 12 December 2018.

MORSE JA, POWELL AN, TETREAU MD. 2006. Productivity of Black Oystercatchers: Effects of recreational disturbance in a national park. The Condor 108:623–633.

NAUGHTON MB, PITKIN DS, LOWE RW, SO KJ, AND STRONG CS. 2007. Catalog of Oregon seabird colonies. Biological Technical Publication FWS/BTPR1009-2007. Washington, DC: US Department of Interior, Fish and Wildlife Service. 487 p. Available from: https://nctc.fws.gov/resources/knowledge-resources/pdf/Oregon-Catalog-seabirds.pdf.

[NABCI] NORTH AMERICAN BIRD CONSERVATION INITIATIVE. 2016. The state of North America's birds 2016. Ottawa, ON: Environment and Climate Change Canada. Available from http://www.stateofthebirds.org/2016/resources/species-assessments. Accessed 12 December 2018.

[ODFW] OREGON DEPARTMENT OF FISH AND WILDLIFE. 2005. Rocky Shoreline section of the Oregon Coast, GIS shapefile. Available from https://www.oregonocean.info/index.php/ocean-documents/maps-data/gis-data/shapefiles/physical-1/earth-1/1048-rocky-shoreline-sections-of-the-oregon-coast-odfw-2005. Accessed February 2016.

[ODFW] OREGON DEPARTMENT OF FISH AND WILDLIFE. 2016. Oregon nearshore strategy. Oregon Department of Fish and Wildlife, Salem, OR. Available from http://oregonconservationstrategy.org/oregon-nearshore-strategy. Accessed 12 December 2018.

ROYLE JA. 2004. *N*-mixture models for estimating population size from spatially replicated counts. Biometrics 60:108–115.

SENNER SE, ANDRES BA, GATES HR (Eds.). 2016. Pacific Americas shorebird conservation strategy. New York, NY: National Audubon Society. 88 p. Available from https://www.fws.gov/migratorybirds/pdf/management/PASCS_final_medres_dec2016.pdf.

SPIEGELHALTER DJ, BEST NG, CARLIN BP, VAN DER LINDE A. 2002. Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society: Series B (Statistical Methodology) 64:583–639.

SPIEGELHALTER DJ, THOMAS A, BEST NG, LUNN D. 2003. WinBUGS version 1.4 User Manual. Cambridge, UK: MRC Biostatistics Unit.

TESSLER DF, JOHNSON JA, ANDRES BA, THOMAS S, LANCTOT RB. 2007. Black Oystercatcher (*Haematopus bachmani*) conservation action plan. International Black Oystercatcher Working Group. Manomet, MA: US Fish and Wildlife Service, Manomet Center for Conservation Sciences. 115 p. Available from http:www.whsrn.org/shorebirds/conservation_plans.html.

TESSLER DF, JOHNSON JA, ANDRES BA, THOMAS S, LANCTOT RB. 2014. A global assessment of the conservation status of the Black Oystercatcher *Haematopus bachmani*. International Wader Studies 20:83–96.

[USFWS] US FISH AND WILDLIFE SERVICE. 2019. Oregon seabird colony catalog – computer database and colony status record archives. Newport, OR: US Fish and Wildlife Service, Oregon Coast National Wildlife Refuge Complex.

US SHOREBIRD CONSERVATION PLAN PARTNERSHIP. 2016. US shorebirds of conservation concern — 2016. http://www.shorebirdplan.org/science/assessment-conservation-status-shorebirds.

WEINSTEIN A, TROCKI L, LEVALLEY R, DOSTER RH, DISTLER T, KRIEGER K. 2014. A first population assessment of Black Oystercatcher *Haematopus bachmani* in California. Marine Ornithology 42:49–56.

WOOTTON JT. 1992. Indirect effects, prey susceptibility, and habitat selection: Impacts of birds on limpets and algae. Ecology 73:981–991.

Submitted 24 December 2018, accepted 10 August 2019. Corresponding Editor: Jeffrey Snyder.