MARBLED MURRELET PRODUCTIVITY MEASURES AT SEA IN NORTHERN CALIFORNIA DURING 2011 AND 2012

AN ASSESSMENT RELATIVE TO REDWOOD NATIONAL AND STATE PARK LANDS

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SUMMARY

This study of Marbled Murrelet productivity off the coast from Redwood National and State Parks was designed to test for an effect of nest predator management in the parks by an increased number of fledglings or a higher ratio of fledglings to older birds offshore from their nesting areas. Replicate vessel transects following the protocol and design of the Northwest Forest Plan population monitoring program were conducted along 100 km of coastline from Point St. George to Trinidad, California, during the main fledging period between 14 July and 22 August of 2011 and 2012.

Summary ratios showed 2.8% and 2.0% of the murrelet population to be fledglings in 2011 and 2012 respectively. This was similar to or lower than earlier surveys in the study area and in the larger region from Coos Bay to Cape Mendocino, and no effect of improved nesting success due to park management could be discerned. We did find evidence of micro-habitat preference and movements of both fledglings and older birds through the study period. Until a sampling design is developed to collect truly representative age ratio and fledgling density data, these measures are best considered indices of productivity rather than population parameters of reproductive output.

INTRODUCTION

Marbled Murrelets (*Brachyramphus marmoratus*) are a federally threatened seabird species that is dependent on mature forest stands for nesting habitat on the west coast of the United States (Nelson 1997). With evidence of poor productivity (McShane et al. 2005), declining populations (Falxa et al. 2011), and a strong relationship between distribution and remaining mature coastal forest habitat (Raphael et al. 2011), there is a need to improve and manage remaining nesting habitat to meet recovery goals. Monitoring population trend of the Marbled Murrelet is a component of the Northwest Forest Plan Effectiveness Monitoring Program (Madsen et al. 1999) and has been carried out along the west coast for the past 12 years (Falxa et al. 2011, Strong 2011), but the only consistent long term effort to assess productivity of the species is in the San Juan Islands (M. Raphael pers. comm.). We used vessel-based surveys to collect data on age ratios and fledgling densities as indicators of productivity of murrelets in coastal waters adjacent to some of the last large stands of habitat in California contained in the Redwood National and State Parks (RNSP) of Humboldt and Del Norte Counties. This second year of the at-sea study was supported by *Kure* and *Stuyvesant* oil spill settlement funds as a means of assessing the effectiveness of marbled murrelet predator management on RNSP lands. It is anticipated that predator management will result in improved marbled murrelet reproductive success. Here we provide findings on productivity indices and distribution of murrelets off shore from RNSP during 2011 and 2012 and drawing from earlier survey work in the region.

METHODS

Survey Protocol

Vessel surveys were made from 7 m Boston Whaler boats equipped for coastal waters. Research equipment included binoculars and micro recorders for each observer, maps covering planned transect lines, GPS and a laser range finder. The deck of the boat was about level with the waterline; so standing observer viewing height was about 2 m above water. The GPS was loaded with the randomly selected transect routes prior to each survey (see below). Two observers and a vessel driver were on board for all transects. Each observer scanned a 90^{o} arc between the bow and the beam continuously, only using binoculars to confirm identification or to observe plumage or behavior of murrelets. Search effort was directed primarily towards the bow quarters and within 50 m of the vessel, so that densities based on the transect line and narrow strip transects were more accurate (Buckland et al. 1993). All Marbled Murrelet detections at any distance were recorded with information on group size and estimated perpendicular distance from the transect line, behavior, age (as After-hatch-year = ‘AHY’, or as Hatch-year = ‘HY’, representing birds that fledged during the survey year), and molt class. All other seabird species within 50 m of the boat and on the water were recorded. Only murrelets and aerial foragers (pelicans, terns, and osprey) were also recorded when flying. Marine mammals and boats were also recorded using line transect methods. Environmental parameters and observing conditions were monitored on all surveys. Data were recorded digital audio recorders and later transcribed and entered on computer. The vessel driver maintained a speed of 10 knots following the transect route, watched for navigational hazards, and paused transects to navigate strategically around birds requiring age determination. The driver participated in searching for murrelets when not otherwise occupied.

Transect layout was the same as used by the NWFP population monitoring effort (see Miller et al. 2006, Raphael et al. 2007). In short, contiguous 20 km coastal sections extending 3 km out to sea are Primary Sampling Units (PSU). PSU are divided into inshore (400 to 2000 m) and offshore (2000 to 3000 m out to sea) subunits. Inshore subunits are sampled for the entire 20-km length of the PSU, and offshore subunits are sampled by a 6 km transect angling across the offshore subunit with a random starting point. The inshore subunit was further divided into four 5 km. long segments which are each surveyed at different distances offshore, such that all habitats (relative to distance from shore) are sampled with equal probability within the subunit. Waters inshore of 400 m are not sampled with the NWFP plan for safety reasons. In this study we sampled the entire study area once at 200 to 350 m offshore. At 10 knots, a PSU survey typically takes about 3 hours.

Age determination techniques followed the basic methods of Strong (1998a), and summarized in Appendix A. Briefly, plumage was categorized into 4 molt class categories of prebasic molt of after-hatch-year (AHY) birds or as hatch-year (HY) plumage. When black and white murrelets (class 4) were detected, the transect survey was paused and close observation of plumage and behavior were made to determine age, because both HY and AHY birds can have a black and white plumage.

Geographic and Temporal Coverage

Inland nesting habitat contained in Redwood National Park in northern Humboldt County is the management area of interest, adjacent to PSUs 12, 13 and 14 (Fig 1). We surveyed PSU's 11 through 15 to account for bird movement at-sea and to sample within a range of shoreline and benthic habitats. Where the shorelines in PSU 13 and 14 are fairly uniformly sandy beach, adjacent PSUs to the north and south have partially to wholly rocky shore, kelp, and embayments, which may be preferred marine habitat by HY murrelets (Kuletz and Piatt 1999, Strong 1998b).

Sampling was conducted within four 10 day sample intervals between 14 July and 22 August following the productivity sampling intervals used by the US Forest Service-Redwood Sciences Laboratories (see Long et al. 2010). This period matches the season when most HY fledge in northern California, and ended early enough to avoid confusion of advanced prebasic molt AHY with HY. The study goal was to obtain 6 replicate samples of each of the 5 target PSU, including one replicate for each of the first two 10-day periods and 2 replicates per PSU for each of the two August sampling periods (3-12 August and 13-22 August), when peak numbers of HY were expected based on fledging dates. An additional survey of waters < 400 m offshore through all 5 PSU was completed on 17 August to check if concentrations of murrelets occurred inshore of usual PSU sampling late in the nesting season.

Analysis

Productivity was measured as a ratio of known-age HY: AHY as well as the number of HY birds detected per km of survey at sea (encounter rate), the latter providing a measure of hatch-year abundance independent of local AHY abundance. Peery et al. (2007) developed a regression-based technique to estimate the proportion of HY fledged to sea by date during the main fledging period, and the method was modified by M. Raphael (USFS PNW Res. Sta.) for use in the Pacific Northwest. This technique generates a date-adjusted estimate of HY based on local

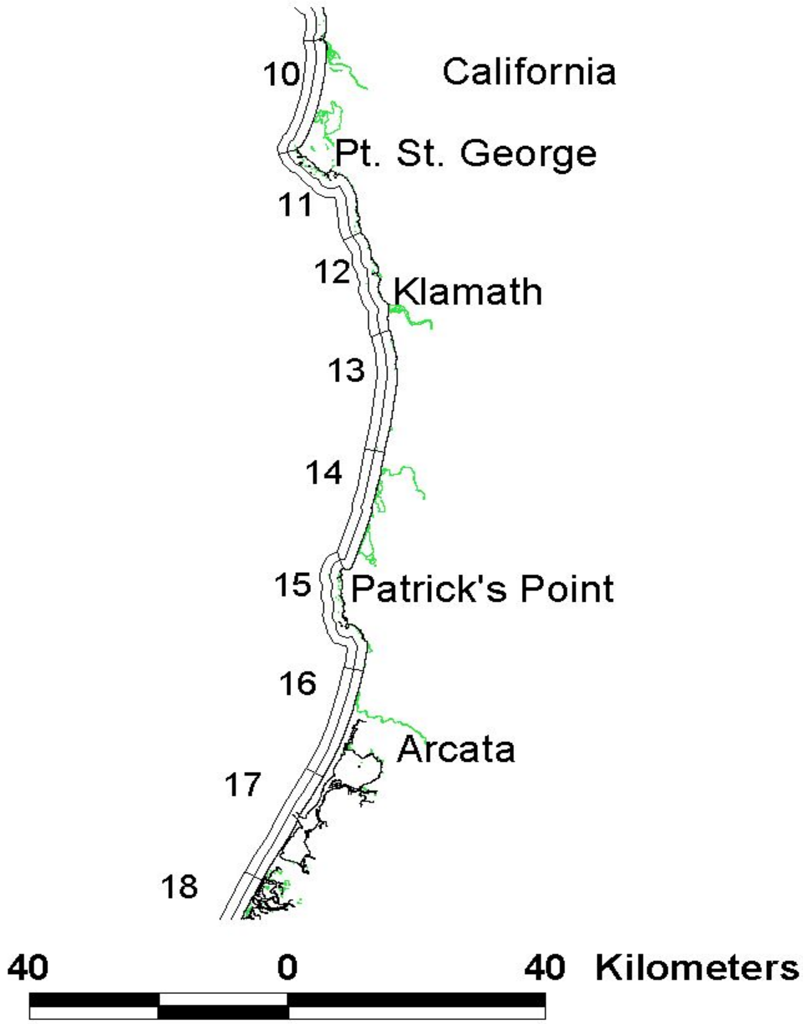

Figure 1. Northern California showing Primary Sampling Unit numbers within the study region (PSU 11 – 15).

nesting chronology, and can provide a confidence interval around HY:AHY point estimates by treating surveys within 10 day time intervals as samples. Only complete PSU samples were used in analyses; the 17 August 2012 near-shore survey was excluded from all analyses except that for Table 5 and Figure 2 which address distribution relative to shore.

Data provided by the US Fish and Wildlife Service, Arcata Office (FWS) and the US Forest Service' Redwood Sciences Laboratories (RSL) were combined with CCR data for 2000 to 2009 for comparisons with prior years (CCR collected all data for years 2010-2012). The FWS-RSL data were collected with the same sampling design and very similar ageing techniques (see Long et al 2010). Kilometers of survey effort for 2000 to 2004 FWS-RSL data were estimated as 26 km per PSU since exact effort information is not available.

RESULTS

Effort

CCR completed 28 PSU samples of the 5 PSU within the 40 day period 14 July to 22 August 2012 (Table 1). Surveys were conducted every day in August when conditions allowed, but bouts of northwest wind caused sampling to be clustered in the first and third weeks of August and, as in 2011, much effort was concentrated at the end of the sampling season (Table 1). Geographic sampling was distributed evenly over the 5 PSU, except for missing one replicate of PSU 11 and one of PSU 13 because of weather constraints. In addition to the PSU sample transects, we conducted a single 101 km long transect through all 5 PSU between 200 and 350 m offshore on 17 August (those data are included only Tables 1 and 5). Samples of PSU 10 and 16 (beyond either end of the study area) were intended, but not completed in August due to time limitations. Fledgling encounter rates correlated well with age ratios, both by 10 day time period and by PSU sample in both years, with a stronger relation in 2012 (r values 0.99 versus 0.76 to 0.78 in 2011, data from Tables 3 and 4). Encounter rates of HY showed a temporal peak at the end of the 2011 sampling period, but in 2012 there were two peaks, one from 24 July - 2 August and one at the end (Table 3).

Age determination

Age determination between advanced molt AHY and HY was effective using the techniques described in Strong (1998a). There was some indication that molt progression was earlier in 2012 over 2011 in that more advanced molt (class 4) AHY were encountered in 2012 (53 versus 44 in 2011) and there were more class 4 birds where age could not be determined (6 versus 1 in 2011, other un-aged birds in Table 1 occurred because no age determination was attempted due to distance or lighting). The file PPMAMU12.XLSX contains detail on how each bird was aged.

Productivity indices

The overall unadjusted 2012 HY /AHY counts in the sampling area after 13 July were 45:2570 (ratio = 0.0175 or 1.72% HY). The date-adjusted HY:AHY ratio was 53:2570 (ratio =0.0206 or 2.02% HY). This is a lower adjusted indice than from 2011 due to both fewer HY and more AHY encountered in 2012 (Table 2). Fledgling encounter rates independent of AHY were also higher in 2011 (Table 2). Unlike 2011 where adjusted ratios were fairly constant through the

Table 1. Summary of Marbled Murrelet productivity assessment surveys completed by CCR in 2011 and 2012. Period is the 10 day interval, PSU locations are shown in Fig. 1, Rep is the sequential replicate number, Draw is the GIS route followed, and Km is the total length of the transect, HY/AHY are counts of hatch-year and older birds aged, and U are counts of unknown age birds.

Date													
2011	**Period**	**PSU**	**Rep**	**Draw**	**Km**	**HY/AHY**	**U**	**PSU**	**Rep**	**Draw**	**Km**	**HY/AHY**	**U**
Jul 14	1	13	1	2	26.0	3 /134	23	14	1		25.7	3 /199	44
17	1	11	1	2	26.1	0 / 52	1	12	1	2	25.7	0 / 7	
18	1	15	1	2	26.2	0 / 40	10						
24	2	13	2	1	25.0	0 / 81	9						
25	2	15	2	3	27.4	1 / 16	6						
Aug 1	2	11	2	3	25.2	2/ 16	5						
2	2	12	2	3	25.0	0/ 30	2						
3	3	13	3	4	26.0	0/ 177	21	14	2	4	23.0	0/ 35	2
9	3	11	3	4	24.8	1/ 85	1	12	3	4	24.8	0/ 43	3
10	3	15	3	4	24.6	4/ 70	8						
13	4	11	4	6	27.0	6/ 128	8	12	4	6	24.8	2/53	2
14	4	13	4	6	26.0	1/ 137	7	14	3	6	25.6	1/ 58	1
15	4	15	4	6	26.5	2/ 39	6						
16	4	11	5	5	25.8	4/ 75	10	12	5	5	24.9	3/ 90	11
17	4	13	5	5	26.5	3/ 82	8	14	4	5	25.9	0/ 22	1
18	4	15	5	5	27.3	4/ 50	6						
19	4	11	6	7	24.1	2/ 90	7						
21	4	14	5	7	26.0	0/ 54							
22	4	12	6	7	24.7	4/ 191	16	13	6	7	26.0	2/ 44	5
2011 TOTALS		28 PSU			716.6	48/2098	233						
2012													
Jul 14	1	11	1	1	25.7	0/ 31	4						
18	1	12	1	2	25.3	0/ 10		13	1	2	27.4	0/ 55	2
20	1	14	1	2	25.7	0/ 102	3	15	1	2	28.1	0/ 3	
26	2	15	2	3	28.0	5/ 49	4						
31	2	11	2	3	23.4	2/ 169	15	12	2	3	23.8	1/ 55	13
Aug 1	2	14	2	3	26.2	0/ 75	10						
4	3	12	3	4	24.3	0/ 45	12	13	2	3	26.1	1/ 43	7
5	3	14	3	4	26.4	0/ 117	9	15	3	4	28.9	3/ 39	7
6	3	11	3	4	26.5	0/ 88	8	12	4	5	24.2	2/ 101	3
8	3	14	4	5	26.1	1/ 46	6	13	3	4	26.9	0/ 124	19
15	4	15	4	5	27.2	6/ 173	19						

Table 1, continued

Date 2012	**Period**	**PSU**	**Rep**	**Draw**	**Km**	**HY/AHY**	**U**	**PSU**	**Rep**	**Draw**	**Km**	**HY/AHY**	**U**
Aug 16	4	11	4	2	25.0	1/ 35		12	5	1	24.1	3/ 130	15
16 ctd.	4	13	4	4	26.2	0/ 56	5	14	5	6	26.6	0/ 157	10
17	4	11 - 15 continuous survey @ 200-350 m offshore									101.0	3/ 19	3
18	4	14	6	7	26.4	1/ 41	4	15	5	6	29.0	8/ 152	19
19	4	12	6	6	24.3	0/ 125	2	13	5	5	27.2	1/ 204	4
20	4	11	5	5	23.8	5/ 129	6						
21	4	15	6	7	29.2	5/ 188	11						
2012 TOTALS			28	PSU	833.2	48/2,586	220						

Table 2. Summary of productivity indices in the study area (PSU 11 - 15) during 2011 and 2012

	2011	2012
Km effort	716.6	732.2
No. of PSU samples	28	28 (plus inshore survey all PSU)
No. of HY	48	45
Date-adjusted no. HY	61	53
No. of AHY	2098	2567
Adjusted HY:AHY ratio	0.0291	0.0206
HY / km (encounter rate)	0.0670	0.0615
AHY / km	2.928	3.506

season, the 2012 date-adjusted ratio showed one peak in the 24 July- 2 August 10 day period and another at the end of the study (Table 3). In both years, however, there was a geographic pattern in which higher ratios and detection rates were found at the north and south ends of the study area (PSU 11 and 15, Table 4). These areas both have rocky and convoluted shorelines, whereas PSU 13 and 14 directly offshore from RNSP have straight sandy shorelines.

Table 3. Summary of Marbled Murrelet productivity data divided into four 10 day periods between 14 July and 22 August during 2011 and 2012 surveys.

	Sampling time period							
	14–23 July		24 July–2 August		3–12 August		13–22 August	
	2011	2012	2011	2012	2011	2012	2011	2012
Km	129.7	132.2	102.6	101.6	123.2	209.5	361.1	289.0
N reps	5	5	4	4	5	8	14	11
HY	6	0	3	8	5	7	34	30
AHY	432	204	143	348	410	625	1113	1390
Ratio	0.014	0.000	0.021	0.023	0.012	0.011	0.031	0.022
Adj. ratio	0.033	0.000	0.033	0.036	0.014	0.013	0.033	0.023
HY / km	0.0463	0.000	0.0292	0.0787	0.0406	0.0334	0.0942	0.104
AHY / km	3.331	1.543	1.394	3.425	3.323	2.983	3.082	4.820

Table 4. Summary of Marbled Murrelet productivity data by 20 Km long Primary Sampling Units along the coast from 14 July to 22 August in 2011 and 2012 (see locations in Fig. 1).

	Primary Sampling Units									
	11		12		13		14		15	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Km	153.0	124.6	149.9	146.0	155.5	133.8	126.2	157.4	132.0	170.4
N reps	6	5	6	6	6	5	5	6	5	6
HY	15	8	9	6	6	2	5	2	5	27
AHY	446	454	414	469	655	482	368	538	215	624
Ratio	0.034	0.018	0.022	0.013	0.014	0.004	0.011	0.004	0.051	0.043
HY / km	0.098	0.064	0.060	0.041	0.058	0.014	0.032	0.013	0.083	0.158
AHY / km	2.915	3.644	2.762	3.212	4.212	3.602	2.916	3.418	1.629	3.662

Distribution of HY and AHY birds

Pertinent to the reliability of productivity indices is the differential distribution of the age groups, AHY and HY. There was evidence of distribution shifts within the productivity sampling period for both age groups, however, correlation between AHY and HY encounter rates was high when using 10 day periods (r= 0.97 for both years, data from Table 3) and between the 5 sampled PSU in 2012 (r=0.81, r= 0.00 in 2011, Table 4).

The near-shore coverage of the entire study area on 17 August was intended to address whether HY were disproportionately concentrated inshore of usual PSU sampling. What we found were remarkably low densities of murrelets as well as all other seabird species (Table 1 and provided data files). However, among the 22 murrelets detected in over 100 km of survey within 350 m of shore on that day, 3 were confirmed fledglings.

To better represent distribution patterns, 10 day periods were combined into early and late fledging (with a division on 2 August), and five categories of distance offshore were specified: less than 800 m, 800 - 1100, 1200-1500, 1600-1900, and the offshore subunit 2000 to 3000 meters from shore. Figure 2 and Table 5 show results of this representation.

Figure 2 shows a pattern suggesting movement offshore from early to late in the fledging period, both for AHY and HY. Peak HY encounter rates were at < 800 m offshore during the early periods, and were found at 1200-1500 m offshore during August of both years (Fig. 2c, 2d). There was some indication of a similar pattern for AHY in 2011 but not so in 2012. In any case, at this level of resolution, concordance can be seen between HY and AHY distribution offshore in Figure 2, which explains the high correlation coefficients from Tables 3 and 4 (sample sizes for regressions based on PSU or time period are too small to assign significance).

The 75th and 95th percentile of encounter rates of HY and AHY highlighted in Table 5 illustrate the concentrations of HY at the north and south ends of the study area late in the season, and shows the area off RNSP (PSU 13, 14) to have high numbers of AHY early in the study period, and high encounter rates of HY during 2011. The pattern of net movement offshore between early and late is also apparent, at least for HY. Where PSU 11 and 15 had high HY encounter rates in 2011, PSU 15 had the maximum encounter rates of HY in 2012, as well as high numbers of AHY in August.

Comparison with Prior Years

When CCR and FWS-RSL data are combined for each year 2000 to 2012 and compared between all of Zone 4 and the study area of this project, one can see that adjusted ratios and encounter rates in 2011 and 2012 were close to the average for the entire Zone and for the study area (Table 6a, 6b). The adjusted ratios show a higher value for the whole Zone than for this study area, but that is because AHY birds are at higher densities in PSU 11-15. Where ratios are slightly below average in 2011 and 2012, HY encounter rates independent of AHY are slightly higher, but in neither case is it a significant difference. Again the differences are because the study area holds relatively high densities of both AHY and HY compared with all of Zone 4.

At an annual scale from Table 6, there was no significant correlation between HY and AHY encounter rates (where there was at smaller scales, see above). However, there was still a significant correlation between HY encounter rates and HY:AHY adjusted ratios ($r=0.782$, $p=0.001$ for Zone 4, $r=0.720$, $p=0.0035$ for PSU 11-15).

Not evident in Table 6 are the time periods and PSU locations of annual surveys throughout Zone 4. Prior to this study, PSU selection for productivity work was more arbitrary and based on logistics and weather. This could have a bearing on results due to annual variation in timing of fledging and uneven geographic distribution of age groups.

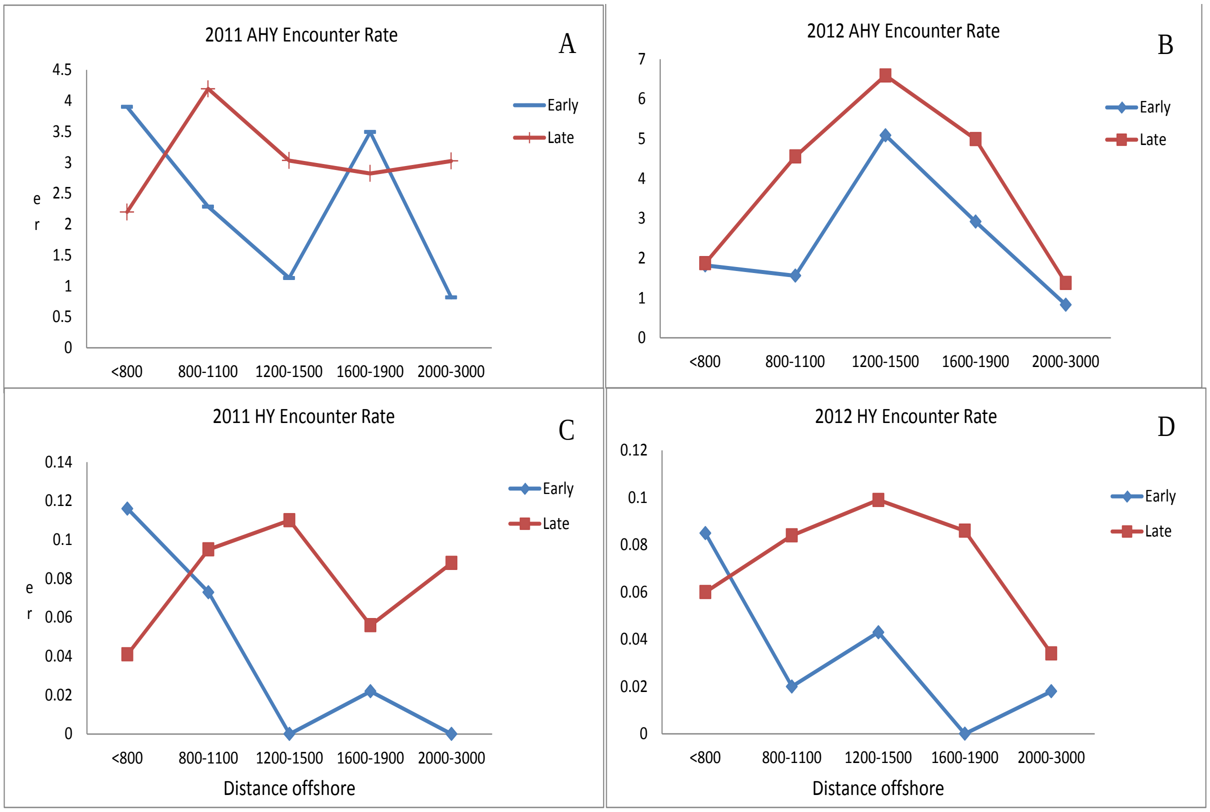

Figure 2. Encounter rates of aged Marbled Murrelets by distance offshore from early (<3 August) and late (> 2 August) surveys in 2011 and 2012.

Table 5. Encounter rates of AHY and HY Marbled Murrelets by PSU[1] in categories of distance offshore during 2011 and 2012. Highlighted are the 75th (yellow) and 95th (orange) percentile of all encounter rates shown for the two age groups.

			2011						2012					
			Distance Offshore						Distance Offshore					
			<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN	<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN
AHY		11	1.729	3.191	0.700	0.300	0.242	1.559	0.000	1.154	10.213	4.523	2.857	3.749
		12	0.360	0.808	0.306	2.148	0.179	0.693	1.707	0.435	2.889	2.000	0.410	1.488
EARLY	PSU	13	5.000	4.878	1.900	7.800	1.689	4.253	1.404	0.385	7.059	1.000	0.625	2.094
		14	15.700		2.400	3.200	2.456	7.891	5.608	4.612	3.322	5.102	0.000	3.729
		15	0.259	0.333	0.816	3.877	0.333	1.075	0.172	0.625	2.927	1.007	0.167	0.980
		MEAN	**3.901**	**2.285**	**1.129**	**3.494**	**0.816**	**2.444**	**1.820**	**1.560**	**5.085**	**2.918**	**0.832**	**2.443**
			<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN	<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN
AHY		11	0.821	4.307	3.190	4.891	4.694	3.596	0.928	0.783	3.751	7.067	2.404	2.986
		12	5.629	3.228	4.096	1.130	3.968	3.715	5.522	4.097	6.770	4.302	1.254	4.389
LATE	PSU	13	1.733	8.013	3.249	2.650	4.875	4.180	2.817	8.977	4.104	3.294	0.952	4.029
		14	0.842	1.407	2.841	2.836	0.240	1.691	1.595	1.969	5.816	5.734	0.937	3.210
		15	1.737	4.244	1.312	1.970	0.787	2.010	0.774	6.113	11.796	4.886	1.600	5.034
		MEAN	**2.199**	**4.195**	**3.033**	**2.823**	**3.025**	**3.088**	**1.872**	**4.553**	**6.589**	**4.990**	**1.378**	3.876
			<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN	<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN
HY		11	0.098	0.106	0.000	0.100	0.000	0.068	0.000	0.000	0.096	0.000	0.079	0.035
		12	0.050	0.000	0.000	0.000	0.000	0.017	0.122	0.000	0.000	0.000	0.000	0.024
EARLY	PSU	13	0.200	0.100	0.000	0.000	0.000	0.060	0.000	0.000	0.000	0.000	0.000	0.000
		14	0.300		0.000	0.000	0.000	0.120	0.000	0.000	0.000	0.000	0.000	0.000
		15	0.000	0.061	0.000	0.000	0.000	0.018	0.259	0.089	0.098	0.000	0.000	0.089
		MEAN	**0.116**	**0.073**	**0.000**	**0.022**	**0.000**	**0.049**	**0.085**	**0.020**	**0.043**	**0.000**	**0.018**	**0.033**
			<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN	<800	800-1100	1200-1500	1600-1900	2000-3000	MEAN
HY		11	0.049	0.082	0.171	0.200	0.167	0.133	0.032	0.064	0.065	0.000	0.164	0.056
		12	0.048	0.085	0.104	0.000	0.168	0.085	0.076	0.089	0.000	0.111	0.000	0.047
LATE	PSU	13	0.000	0.150	0.107	0.000	0.000	0.057	0.000	0.000	0.050	0.049	0.000	0.017
		14	0.000	0.000	0.043	0.000	0.000	0.010	0.039	0.000	0.049	0.039	0.000	0.024
		15	0.117	0.186	0.130	0.067	0.113	0.122	0.127	0.261	0.322	0.219	0.040	0.177
		MEAN	**0.041**	**0.095**	**0.110**	**0.056**	**0.088**	**0.080**	**0.060**	**0.084**	**0.099**	**0.086**	**0.034**	**0.064**

[1]The continuous near-shore survey of PSU 11-15 on 17 August 2012 is included in Table 5 data.

Data Products

Companion products with this report are two electronic database versions of the data collected, which are being provided separately. These files are:

PP12SEGT.XLSX (1,264 records): Detection for all marine species summed by each transect segment during transects for this study.

PPMAMU12.XLSX (1,281 records): All individual Marbled Murrelet records from the field work for this study in 2012

CCRdatafieldsDOC.DOCX describes the contents of fields in the above databases.

Table 6a. Productivity indices of Marbled Murrelets based on 14 July to 22 August surveys in all of

Zone 4: Coos Bay, OR, to Shelter Cove, CA. Includes data collected by both FWS-RSL (2000-2009) and CCR (2000-2012) sampling efforts. Indices use the date-adjusted number of HY birds to account for different sampling dates across years. RSL sampling effort from 2000 to 2004 were estimated as 26.0 km/PSU since original data are unavailable.

	Sampling Effort	Number of Murrelets			Indices	
YEAR	Km Sampled	AHY	HY	Adj. HY	Adj. Ratio	HY/ Km
2000	1149	1519	64	92.5	0.061	0.081
2001	1122	1088	40	50.0	0.046	0.045
2002	390	303	4	9.5	0.031	0.024
2003	651	1027	23	38.2	0.037	0.059
2004	611	586	12	14.8	0.025	0.024
2005	414	539	4	5.4	0.010	0.013
2006	203	146	2	4.7	0.032	0.023
2007	170	269	17	18.7	0.070	0.110
2008	656	783	42	61.8	0.078	0.094
2009	623	1120	27	37.7	0.034	0.061
2010	432	640	22	32.6	0.051	0.075
2011	819	2120	49	63.7	0.030	0.078
2012	809	2609	47	57.8	0.022	0.071
Weighted Mean					0.0412	0.0602

Table 6b. Productivity indices of Marbled Murrelets based on 14 July to 22 August surveys in the study area region for this project; Pt. St. George to Clam Beach, CA (PSU 11-15). Includes data collected by both FWS-RSL and CCR sampling efforts. Indices use the date-adjusted number of HY birds to account for different sampling dates across years. RSL sampling effort from 2000 to 2004 were estimated as 26.0 km/PSU since original data are unavailable.

	Sampling Effort	Number of Murrelets			Indices	
YEAR	Km Sampled	AHY	HY	Adj. HY	Adj. Ratio	HY/ Km
2000	364	950	12	19.3	0.020	0.053
2001	312	664	17	20.6	0.031	0.066
2002	78	118	0	0	0.000	0.0
2003	249	665	10	13.7	0.021	0.055
2004	302	321	9	11.4	0.036	0.038
2005	205	438	2	3.2	0.007	0.016
2006	73	62	2	4.7	0.076	0.064
2007	27	52	1	1.6	0.031	0.059
2008	264	527	26	37.0	0.070	0.140
2009	263	804	11	13.1	0.016	0.050
2010	155	361	8	12.6	0.035	0.081
2011	717	2098	48	61.3	0.029	0.085
2012	732	2567	45	53.0	0.021	0.072
Weighted Mean					0.0281	0.0663

DISCUSSION

This research project is the first of its kind in the intensity of at-sea survey coverage in a focal area to assess productivity of Marbled Murrelets. Though the field methods and sampling regime were feasible and largely achievable in this two year effort, no signal of higher fledging success could be discerned for the area off RNSP for 2011-2012 compared to previous years, although productivity sampling prior to 2011 was not as consistent, intensive, or representative as in this study. There was evidence for movement of fledglings from their first point of arrival at sea to preferred habitats within days to weeks of fledging, and late-season shifts in location of molting adult birds further confounded fine scale use of age ratios. Earlier work from central Oregon showed murrelet and Common Murre HY encounter rates to be correlated over years, and that HY numbers of both species were higher in years with high upwelling indices in spring (Strong 2008). It is probable that annual variation in marine conditions and bird movement make it impractical to detect what is likely a relatively subtle effect of nesting habitat management on productivity, using the methods of this study. If the study area were expanded to increase sample sizes and thus statistical power, the results would be comparably diluted by sampling birds from outside the area of interest, thus confounding interpretation.

Given the small proportion of HY to AHY, mis-ageing small numbers of HY as AHY could have a large effect on productivity indices. We have good confidence in our age determination assessments and find no reason why the 7 black and white unknown-age birds examined in this study (1 in 2011, 6 in 2012) are more likely to be fledglings than older birds. The majority of unknown-age birds (232 in 2011 and 213 in 2012 from Table 1) were because they were too far to see any plumage features for the observing conditions, and no age attempt was made. Missed detections of HY birds in greater proportion than missed AHY birds would have a similar impact on the indices as mis-ageing. There is no ready way to know if HY are less likely to be detected due to behavior or plumage, but the evasive diving behavior of HY makes this a possibility that cannot be ruled out. An analysis of program DISTANCE detection curves for HY and AHY in different observing conditions could shed some light on this, were there an adequate sample of HY detections.

Though I found inconclusive results for the primary intent of this study, valuable data were obtained on the late summer marine avifauna off RNSP, and patterns of seasonal shifts in murrelet distribution were clarified. In both years, there was evidence of HY habitat preference for the convoluted and rocky shores at either end of the study area. Strong (1998b) speculated on a HY preference for this type of habitat in Oregon, and also noted certain semi-protected areas where AHY in advanced molt would concentrate at the end of the nesting season. Carter (1984) and Carter and Stein (1995) described a similar pattern of AHY movement and concentration in semi-protected areas of Barkley Sound, British Colombia. Where Peery et al (2007) found no evidence of movements or differential distribution of HY and AHY in central California, Kuletz and Piatt (1999) described dramatically different distribution of the two age classes and small areas where HY concentrated. The pattern in our study area appears to be between these extremes, both geographically and behaviorally. At a PSU scale of resolution (20 km), the correlation between AHY and HY encounter rate and between HY encounter rate and age ratios suggest that AHY and HY have similar distributions. I suspect that the concentration of HY off RNSP (PSU 13, 14) early in 2011 moved to preferred habitats by the later fledging period (from

Table 6). There are several indications that 2012 was an earlier fledging season: from the earlier molt progression of AHY, from more HY seen in Zone 3 during July 2012, and from the date-adjusted peak in HY encounter rates in late July 2012 (Table 3). This would explain the higher densities of HY in PSU 15 in the earlier fledging period in 2012 if they had already moved from the sandy shores of PSU 13 and 14 (Table 5).

We were surprised to find so few murrelets when surveying the very nearshore of the entire study area on 17 July 2012. Dense concentrations of molting AHY birds were encountered near-shore in PSU 12 during 2011 and have been seen in similar habitats in earlier years, but not so in 2012. Very low densities of other seabird species on that survey suggests prey resources were minimal within 400 m of shore in August 2012. The fact that 3 of the 22 aged murrelets were fledglings on that survey is suggestive of HY preference for the very near-shore habitats. Ralph and Long (1995) found no difference in distribution relative to shore between HY and AHY in northern California, but their sample of the very near-shore (<400 m) was small and in select locations.

Age ratios for Marbled Murrelets in this and other studies (Beissinger 1995, Kuletz and Kendall 1998, Long et al. 2010, Mason et al. 2002, Peery et al. 2007, Raphael pers. comm., Strong 2011,) have found consistently low ratios, between 1.6% and 8% HY, which has led to demographic models of declining populations (Beissinger 1995, McShane et al. 2005). Though there is evidence of some decline in Conservation Zone 4 which includes our study area (Miller et al.2012), it is non-significant and certainly less than the models predict. Given the divergence between modeled population decline and observed trend, I believe HY are missed at sea, either by missed detections in the transect due to evasive dive behavior or by concentrations of HY in the very near-shore which are under sampled or not sampled. Until we understand distribution of HY and AHY enough to obtain representative samples, I suggest that age ratios be considered indices of productivity rather than measures of reproductive output, as was recommended by Kuletz and Kendall for Alaska (1998). I would further recommend that both ratios and HY encounter rates be reported as productivity indices, since they provide different but complementary information as we continue to learn about this enigmatic species.

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Appendix A. A description of ageing techniques used in this study.

During surveys, if an observer detects a murrelet that appears 'black and white' at any distance, they ask the driver to pause to inspect the bird(s) with binoculars. By definition, if age cannot be easily determined when a clear view of plumage is seen, it is a class 4 bird. Once a class 4 bird is called out, the driver will maneuver to obtain best lighting and slowly approach the subject at a slight angle, and both observers will use binoculars to examine plumage and behavioral details. If multiple class 4 detections are made, the first detection will be pursued to determine age, and then subsequent ones will be pursued if they are re-located. We will spend up to 10 minutes in making an age determination. Transects resume at the same place as paused, using the GPS 'MOB' feature to find the location.

Codes and descriptions of age determination criteria used in the AGE1, AGE2, …AGE6 fields in file PPMAMU12.XLSX are as follows. Note that these codes are used (fields filled in) only when molt class is C4 (or M4, advanced molt AHYor juvenile).

The first 1-2 letters of the code is the age determination, designated:
J Confirmed HY Juvenile
JU Unconfirmed HY
A Confirmed AHY
AU Unconfirmed AHY
U Unknown age bird
JU and AU determinations are included as HY and AHY in the database, respectively.

Following letters are code for criteria seen that allow the age determination. The first set of codes apply to HY as: Z Crisp, sharply delineated black and white overall appearance, or glossy even dark plumage on top
FW Full wing outline, no molt apparent on wing
WB White belly and chest, usually viewed when the bird dives
B Behavioral indication of age or molt status. The actual information should be in the NOTES field, and includes (juvenile behaviors): Rapid or evasive diving or flight, lack of flapping upon coming to the surface, separation from pair or group members, or (AHY behaviors): reluctance to dive when first approached, immediate wing-flapping upon surfacing, strong pairing or synchronous diving with group members.
FF Fine Flecking on breast, giving an even coloration pattern at a distance
ET Egg tooth visible on dorsal tip of bill

And codes indicating AHY age:
R. Brown feathers visible on back or in the neck or breast, viewed in good front lighting
P, OP, or IP Primary flight feathers missing (OP indicating outer primaries missing giving the wing outline a stubby appearance, or IP for inner primaries or secondaries missing), P is nonspecific flight feather molt.
DB Dark belly visible when bird dives. Ventral feathers, usually immersed, are the last body feathers to molt and are an effective ageing criteria.
B Behavior, see above.
2 Strong pairing behavior.