NORTHWESTERN NATURALIST 82:41–51 AUTUMN 2001

MORPHOMETRIC VARIATION IN MARBLED MURRELETS, *BRACHYRAMPHUS MARMORATUS*, IN BRITISH COLUMBIA

CINDY L. HULL[1], BRETT A. VANDERKIST, AND LYNN W. LOUGHEED[2]
CWS/NSERC Wildlife Ecology Research Chair, Department Biological Sciences, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6 CANADA

GARY W. KAISER
Canadian Wildlife Service RR1 5421 Robertson Road, Delta, BC V4K 3N2 CANADA

FRED COOKE
CWS/NSERC Wildlife Ecology Research Chair, Department Biological Sciences, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6 CANADA

ABSTRACT—Morphometrics (culmen length, bill height, bill width, wing chord length, and tarsus length) were taken on 664 marbled murrelets at Desolation Sound and Mussel Inlet, British Columbia, during 1994 to 1997, in order to assess morphological differences within and between populations and the accuracy of a discriminant function analysis to identify the sex of birds. An assessment of inter- and intra-observer variability in measurements was also made. Significant inter-observer effects and some intra-observer effects were found. Data from recaptured murrelets indicated they had decreased in size with age, which was attributed to inter-observer effects. Wing chord length had the highest measurement error (66.8%) among observers and tarsus length had the lowest error (36.8%). Deviations of measurements from the mean were compared among years and sites. No inter-annual differences were detected in any morphometric at Desolation Sound. Significant differences in culmen length, wing chord length, and tarsus length were found between birds from Mussel Inlet and Desolation Sound, which might indicate discrete populations. The degree of sexual dimorphism in this species was small (measurements of females average 98% of corresponding measurements of males) and discriminant function analysis revealed only about a 70% success rate in allocating birds to sex; therefore, its widespread use in this species is not recommended. Future studies of marbled murrelets, or other avian species, which involve large numbers of personnel, should incorporate extensive training of all observers, with data continually cross-checked in order to minimize intra- and inter-observer differences in measurements.

Key words: marbled murrelet, *Brachyramphus marmoratus*, morphometrics, Desolation Sound, Mussel Inlet, British Columbia

Morphological measurements of birds are a valuable means of describing differences among individuals, cohorts, populations, and closely related species (Barrowclough 1992; Dzubin and Cooch 1992). They can also be used to accurately and reliably identify the sex of individuals with monomorphic plumage (for example, Counsilman and others 1994; Koffijberg and van Eerden 1995; Phillips and Furness 1997; Hedd and others 1998). However, for some avian species, morphological descriptions of populations are limited, as is an assessment of the use of morphometrics to identify the sex of birds in the field.

Marbled murrelets, *Brachyramphus marmoratus,* are small alcids (family Alcidae) found along the Pacific coast of North America from northern California to Alaska. To date only 2 studies have described the morphometrics of this species, 1 at Langara Island (Queen Charlotte Islands), British Columbia, Canada, and

[1] Present address: *Environmental Services, Hydro Tasmania, GPO Box 355, Hobart, Tasmania 7001, AUSTRALIA.*
[2] Present address: *Estacian Cientifica Charles Darwin, PO Box 17-01-3891, Quito, EQUADOR.*

the other in Alaska (Sealy 1975; Pitocchelli and others 1995); therefore, little is known of the discreteness of populations within the range of the species. Further, like most alcids, marbled murrelets are monomorphic in plumage and body size (Bedard 1985) and, therefore, cannot be sexed in the hand. Although a reliable molecular technique for sexing them has recently been established (Vanderkist and others 1999), it necessitates taking a sample of blood and having expertise in DNA laboratory techniques. Therefore, it would be advantageous if a technique for reliably and accurately determining the sex of marbled murrelets in the field was established. While both previous studies described morphological differences between the sexes of murrelets, neither assessed the accuracy and reliability of using morphometric characters to identify the sex of individuals.

Before a discriminant function for determining the sex of individuals of a species can be used, the extent of variation within the species needs to be known, as do the biases from intra- and inter-observer inconsistencies (Lougheed and others 1991; Phillips and Furness 1997). Few seabird studies have assessed the effect of inter-observer differences in measurement techniques (Barrett and others 1989), although the use of a number of observers is often necessary in many longer-term studies.

The aims of this study were to: (1) describe aspects of the morphology of marbled murrelets from 2 sites in coastal British Columbia and compare the discreteness of these populations to data from other populations, (2) assess morphological variation of murrelets among years and times of day (to determine if morphologically dissimilar parts of the population use the inlets at different times of day), (3) determine if morphometric characters could be used to accurately identify the sex of marbled murrelets, and (4) assess the degree of inter- and intra-observer variability in measurements throughout the study.

STUDY AREA AND METHODS

Field work in British Columbia was undertaken at Desolation Sound (50°04′N, 124°42′W) from May to August, 1994 to 1997, and at Mussel Inlet (52°51′N, 128°10′W, 380 km north of Desolation Sound) from June 24 to July 9, 1997. Marbled murrelets were captured using a shallow-water mist net system (Burns and others 1995; Kaiser and others 1995; Derocher and others 1996) and by 'night-lighting' (modified from Whitworth and others 1997). Mist nets were operated for 2 to 3 hr around dusk (2000 to 2300, local time) and at dawn (0400 to 0700), with birds being caught as they moved to and from forest areas, presumably on foraging trips. Night-lighting was carried out in the open waters of Desolation Sound from mid-May to early August 1997 and in Mussel Inlet from June 24 to July 9, 1997. Birds were caught at night (2300 to 0500) when they were on the water, by searching in boats using spotlights. Once a bird was spotted it was approached slowly and scooped into the boat using a landing net. Night-lighting allowed the capture of breeding birds earlier in the season than did mist-netting and the capture of recently fledged juveniles for the 1st time at Desolation Sound.

Captured birds were weighed and banded with stainless steel Canadian Wildlife Service/U.S. Fish and Wildlife Service bands. The following morphometrics were taken to the nearest 0.1 mm, using calipers except where stated (based on Prater and others 1977): flattened wing chord length (measured from the wrist joint to the tip of the longest primary using a metal ruler), length of exposed culmen, bill width (measured just anterior of the nares), bill height (measured just anterior to the edge of the cuticle), and tarsus length (measured from the proximal end of the tarsus at the inter-tarsal joint to the foot scale at which the toes emerge). No tarsus measurements were taken at Desolation Sound during 1995). We report morphometric details as mean ± standard deviation.

Two ml of blood were taken from the tarsal vein to determine the sex of individuals by using the molecular technique of Vanderkist and others (1999). The birds were then released.

Inter-observer Effects

More than 20 people measured marbled murrelets during this study. The degree of consistency in measurements among observers (Barrett and others 1989; Hamer and Furness 1991) was assessed within each year. Data were used from observers who had measured a minimum of 6 murrelets; because there was only 1 measurer in 1994, within-year comparisons were only made using data from 1995 to 1997. Two observers worked on the program for >1 yr and their data were compared among years in an effort to ascertain whether inter-annual variability in marbled murrelets was real or as a result of inter-observer effects.

The morphometrics of marbled murrelets recaptured during the study period were also assessed to determine if morphological changes occurred over time, and to get an estimate of percent measurement error (%ME) for each morphological character (see Bailey and Byrnes 1990). Because only 1 murrelet was recaptured >1 time, comparisons were made between the original capture year and the subsequent recapture year. Percent ME was calculated by determining the within and among bird components of variance and then using a formula based on Bailey and Byrnes (1990) (but, as recaptured birds were not always measured by the same observer, this is an adaptation of the Bailey and Byrnes model):

$$\%ME = [S_{within}^2/S_{among}^2 + S_{within}^2)] \times 100$$

Morphometric Comparisons

Adult and recently fledged juvenile marbled murrelets were assessed separately, and only birds that had been sexed using the molecular technique (Vanderkist and others 1999) were used in the analyses. Juveniles were determined by plumage (Carter and Stein 1995) and the presence of egg teeth (during this study some marbled murrelets were observed to have 2 egg teeth).

In order to examine inter- and intra-population variation, comparisons were made between adults and juveniles (the latter were only caught in 1997), sexes, years, sites (Desolation Sound versus Mussel Inlet), methods (mist-netting versus night-lighting), and capture sessions (morning, evening, and all night). Data from the most experienced observers with the largest sample sizes were used in the analyses. Comparisons of culmen length and wing chord length among years, sexes, sites, methods, and sessions were made using ANOVAs and *t*-tests. Due to lack of normality in the data that transformations did not resolve, the other variables (bill width, bill height, and tarsus length) were compared using non-parametric Mann-Whitney and Kruskal-Wallis tests. In order to remove inter-observer effects when assessing inter-annual and site differences, the deviation of each measurement from the mean of all mea-

TABLE 1. Morphometric variables of marbled murrelets during each year of the study at Desolation Sound (DS) and Mussel Inlet (MI), British Columbia. DSJ = Desolation Sound juveniles; other data are for adults. Values are mean ± SD; sample sizes are in parentheses.

Year	Site	Sex	Wing chord length (mm)	Culmen length (mm)	Bill width (mm)	Bill height (mm)	Tarsus length (mm)
1994	DS	Male	133.8 ± 3.9 (48)	17.0 ± 1.1 (47)	5.3 ± 0.3 (48)	6.6 ± 0.3 (48)	21.1 ± 1.0 (48)
		Female	131.7 ± 3.9 (19)	17.4 ± 0.9 (19)	5.3 ± 0.4 (19)	6.4 ± 0.2 (18)	20.7 ± 1.2 (19)
1995	DS	Male	132.2 ± 3.3 (68)	18.2 ± 0.9 (70)	4.0 ± 0.4 (70)	5.8 ± 0.3 (70)	—
		Female	130.3 ± 2.6 (38)	17.6 ± 1.1 (39)	3.9 ± 0.4 (39)	5.6 ± 0.4 (39)	—
1996	DS	Male	132.7 ± 4.1 (57)	18.0 ± 0.9 (57)	4.1 ± 0.6 (57)	6.0 ± 0.4 (57)	16.9 ± 0.6 (45)
		Female	131.5 ± 3.6 (37)	17.7 ± 0.8 (37)	4.0 ± 0.4 (37)	5.9 ± 0.3 (37)	16.8 ± 0.8 (29)
1997	DS	Male	133.1 ± 3.7 (142)	17.9 ± 0.8 (142)	4.0 ± 0.3 (142)	5.8 ± 0.3 (142)	17.2 ± 0.8 (142)
		Female	131.1 ± 3.2 (107)	17.4 ± 0.9 (108)	4.0 ± 0.4 (106)	5.7 ± 0.3 (107)	16.9 ± 0.6 (107)
1997	MI	Male	133.8 ± 3.9 (59)	17.2 ± 0.9 (58)	4.0 ± 0.3 (59)	5.8 ± 0.3 (58)	17.7 ± 1.2 (58)
		Female	132.0 ± 3.0 (60)	17.0 ± 1.0 (59)	3.9 ± 0.4 (60)	5.7 ± 0.3 (60)	17.8 ± 1.5 (60)
1997	DSJ	Male	122.0 ± 5.8 (15)	14.7 ± 1.3 (15)	3.6 ± 0.5 (15)	5.2 ± 0.3 (15)	16.7 ± 0.6 (15)
		Female	120.3 ± 5.6 (12)	14.6 ± 1.5 (12)	3.4 ± 0.4 (12)	5.2 ± 0.3 (12)	16.6 ± 0.8 (11)
Total *n*			662	663	664	663	534

surements was calculated. These were then compared using ANOVAs and *t*-tests.

We were interested in determining if morphologically dissimilar murrelets (which could represent different age classes) were caught at different times of day or with the different capture methods at Desolation Sound. As a male-biased sex ratio has been found in birds captured using mist-netting, but not night-lighting at this site (Vanderkist and others 1999), we wanted to assess whether this pattern was reflected in other characters. Comparisons among sites and methods were made using data from only 1997, as this was the only year work was conducted at Mussel Inlet and when night-lighting was used. There were insufficient samples to examine methods and capture sessions during any year other than 1997. Comparisons among methods and capture sessions were made using data collected by 1 observer to avoid inter-observer effects in this test.

Discriminant Function Analysis

Discriminant function analysis (DFA) was conducted using all variables to determine if male and female marbled murrelets could be accurately assigned to sex using morphometric characters. The accuracy of the DFA was cross-checked using a jacknife analysis (Tabachnik and Fiddell 1989). Each variable was then dropped and the DFA re-run to determine if accuracy could be improved. A discriminant formula was derived using variables that resulted in the most accurate DFA. Due to significant differences among years and sites the DFA was conducted on data from only 1 year and 1 site (1997 birds at Desolation Sound, as this data set had the largest sample size). Due to significant inter-observer differences a 2nd DFA was performed on murrelets measured by only 1 person (from 1997, the observer with the largest sample size). DFAs were conducted on adults and juveniles separately, and between adults and juveniles within each sex.

RESULTS

A total of 937 marbled murrelets were captured from 1994 to 1997 at Desolation Sound ($n = 818$), and Mussel Inlet ($n = 119$) during 1997. Excluding birds that could not be sexed, or were recaptured (assessed separately), the morphometrics of 664 murrelets (391 males and 273 females) were available for analysis (Table 1).

Inter-observer Effects

Significant differences were found among observers' measurements in some variables (Fig. 1). Bill width, wing chord length and culmen length were the most inconsistent among observers (Table 2). Inter-annual comparisons of measurements made by the same observer (observers 1 and 2) were more consistent than those found in the entire data set. No significant differences were found between years in any variables measured by observer 1, while male wing chord length and female bill height measured by observer 2 were significantly different between years (Table 2).

The deviation of male wing chord length and female bill width from the mean of all measurements remained significantly different between Mussel Inlet and Desolation Sound (wing chord length: $F_{3, 157} = 4.2$, $P < 0.007$; female bill width: $F_{3, 98} = 8.7$, $P < 0.0001$; other variables: $P > 0.05$).

Sixty-six marbled murrelets were recaptured in different years (Table 3). Significant differences were found between the 2 measurement periods in bill height ($U = 2983.5$, $P < 0.05$), bill width ($U = 2949.5$, $P < 0.05$), and tarsus length ($U = 411.0$, $P < 0.05$), but not in wing chord length ($t_{97} = 1.0$, n.s.) or culmen length ($t_{96} = 0.06$, n.s.). In all cases the morphometrics of murrelets were smaller upon recapture than during the original measurement (bill height: year 1, 6.1 ± 0.4 mm, $n = 51$; year 2, 5.8 ± 0.4 mm, $n = 51$; bill width: year 1, 4.5 ± 0.8 mm, $n = 51$; year 2, 4.1 ± 0.6 mm, $n = 51$; tarsus

→

FIGURE 1. Box plots of culmen length, bill height, bill width, wing chord length and tarsus length measured by different observers from 1994 through 1997. The center line is the median, the length of the box is the range within which the central 50% of values fall. The long lines represent the range in which 75% of values fall. An asterisk denotes an outlier (1.5 times the H-spread or inter-quartile range) and an open circle represents an extreme outlier (3 times the H-spread).

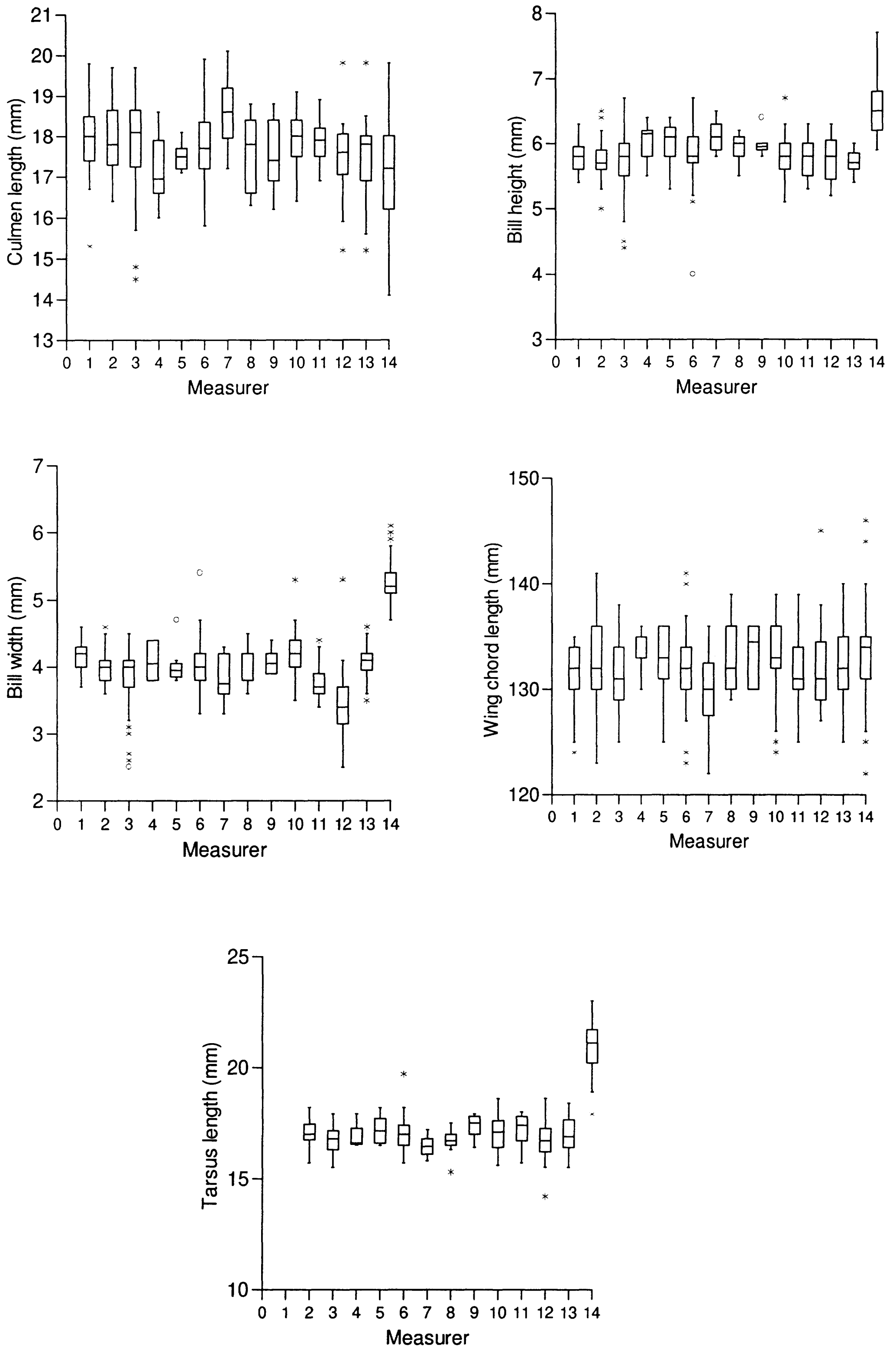
Culmen length (mm)
Measurer
Bill height (mm)
Measurer
Bill width (mm)
Measurer
Wing chord length (mm)
Measurer
Tarsus length (mm)
Measurer

TABLE 2. Statistical significance of variation in the measurements of adult marbled murrelet morphometrics by different observers and by the same observer in different years. Level of significance are indicated by * ($P < 0.05$), ** ($P < 0.01$), *** ($P < 0.001$); otherwise $P > 0.05$.

	Among observers (number of observers)			Within observers, between years	
Morphometric	1995 ($n = 3$)	1996 ($n = 5$)	1997 ($n = 8$)	1995 to 1996	1996 to 1997
Wing chord length:					
Males	$F_{2, 70} = 0.36$	$F_{2, 46} = 3.19$*	$F_{2, 120} = 1.1$	$t_{17} = 0.6$	$t_{46} = 2.2$*
Females	$F_{2, 36} = 4.0$*	$F_{2, 21} = 0.8$	$F_{6, 68} = 1.02$	$t_{14} = 1.1$	$t_{14} = 0.7$
Culmen length:					
Males	$F_{2, 70} = 1.64$	$F_{2, 46} = 2.03$	$F_{2, 120} = 0.6$	$t_{17} = 1.0$	$t_{44} = 0.02$
Females	$F_{2, 37} = 0.44$*	$F_{2, 21} = 5.4$*	$F_{6, 68} = 2.4$**	$t_{28} = 1.3$	$t_{17} = 0.2$
Bill width:					
Males	$H_2 = 6.65$*	$H_4 = 6.13$	$H_7 = 39.5$***	$U = 990.0$	$U = 487.0$
Females	$H_2 = 13.81$***	$H_2 = 1.19$	$F_6 = 17.1$**	$U = 345.0$	$U = 402.5$
Bill height:					
Males	$H_2 = 1.87$	$H_4 = 7.57$	$H_7 = 7.8$	$U = 987.0$	$U = 566.0$
Females	$H_2 = 3.48$	$H_2 = 4.4$	$H_7 = 3.09$	$U = 328.0$	$U = 340.5$
Tarsus length:					
Males	—	$H_4 = 6.82$	$H_7 = 4.2$	—	$U = 339.0$
Females	—	$H_2 = 0.26$	$H_7 = 13.5$*	—	$U = 391.0$

length: year 1, 19.8 ± 2.4 mm, $n = 18$; year 2, 17.5 ± 1.1 mm, $n = 18$). The % ME was highest for wing chord length (66.8), followed by bill height (55.5), culmen length (53.0), bill width (44.2), and tarsus length (36.8).

Morphometric Comparisons

Adult marbled murrelets were significantly larger than recently fledged juveniles with 1 exception. Female adults and juveniles did not differ significantly in tarsus length (Tables 1 and 4).

When deviations from the mean were examined, there also were no significant differences in any morphometric variable among years in either sex (wing chord length: males $F_{2, 158} = 2.8$, females $F_{2, 99} = 0.2$; culmen length: males $F_{2, 159} = 0.8$, females $F_{2, 100} = 0.6$; bill width: males $F_{2, 156} = 0.5$, females $F_{2, 99} = 2.8$; bill height: males $F_{2, 156} = 1.3$, females $F_{2, 96} = 1.3$; tarsus length: males $t_{53} = 1.4$, females $t_{24} = 0.8$). Using data from 1 observer revealed no significant differences in males among capture sessions in any variable (insufficient data to test in females), or in any variable in both sexes using different capture methods (Table 5).

TABLE 3. Recaptures of marbled murrelets from 1994 through 1997.

Year	Same year recapture	Inter-year recapture	Total
1994	2	1	3
1995	10	9	19
1996	3	10	13
1997	26	46	72
Total	41	66	117

Comparison of deviations of birds from Mussel Inlet to those at Desolation Sound indicated that male murrelets from Mussel Inlet had significantly smaller culmen lengths ($t_{95} = 5.4$, $P < 0.0001$) and tarsus lengths ($t_{75} = 3.3$, $P < 0.002$) but were not significantly different in the other variables (wing chord length $t_{104} = 0.8$, bill width $t_{92} = 0.4$, bill height $t_{90} = 0.8$). Female murrelets differed significantly between the 2 sites in culmen length ($t_{112} = 3.0$, $P < 0.003$), wing chord length ($t_{126} = 2.0$, $P < 0.05$), and tarsus length ($t_{114} = 3.4$, $P < 0.001$), but not in bill width ($t_{117} = 1.9$, $P > 0.05$) or bill height ($t_{117} = 1.5$, $P > 0.05$).

Discriminant Function Analysis

Male and female murrelets differed significantly in size during all years of the study (overall, female measurements as a percentage of male measurements were: wing chord length 98.6%, culmen length 97.8%, bill width 97.8%, bill height 98.1%, and tarsus length 98.2%; Tables 1 and 6). However, the variables that differed were not consistent each year. During 1994 adults differed only in bill height, during 1995 wing chord and culmen length were different, no variables differed in 1996, and in

TABLE 4. Statistical significance of differences in morphometric variables between adult and juvenile male and female marbled murrelets from Desolation Sound in 1997.

Variable	Adults versus juveniles: Males	Adults versus juveniles: Females
Wing chord length	$t_{155} = 7.3, P < 0.001$	$t_{109} = 6.5, P < 0.0001$
Culmen length	$t_{155} = 9.2, P < 0.001$	$t_{120} = 6.4, P < 0.0001$
Bill width	$U = 11756.5, P < 0.05$	$U = 6971.0, P < 0.05$
Bill height	$U = 12056.5, P < 0.05$	$U = 7173.5, P < 0.05$
Tarsus length	$U = 11582.0, P < 0.05$	$U = 6778.0, P > 0.05$

1997 wing chord length, bill height, and tarsus length were significantly different (Tables 1 and 6). Significant differences in bill width, bill height, and tarsus length were found between the sexes in juveniles, with males larger in all variables than females (Tables 1 and 6).

The DFA conducted on 1997 adult murrelets from Desolation Sound accurately assigned 66% overall to sex (62.0% males and 70.1% females). With cross-validation the accuracy was reduced to 65% overall (62.0% males and 67.9% females). The most accurate DFA was achieved by using all variables. The derived discriminant formula was:

$$D = 31.5 - 0.5\text{ (culmen length)} - 0.6\text{ (bill height)} + 0.6\text{ (bill width)} - 0.2\text{ (wing cord length)} - 0.2\text{ (tarsus length)}$$

When data are applied to this formula, those >0 are males and those <0 are females.

Using data from only 1 observer improved the accuracy of the DFA to 76% overall (71.4% females and 79.4% males), and with cross-validation accuracy improved to 69% (71.4% females and 67.6% males). Leaving out bill width provided the most accurate result, with the following formula being generated:

$$D = 53.8 - 0.6\text{ (culmen length)} - \text{bill height} - 0.3\text{ (wing)}$$

DISCUSSION

The data collected during this study have provided the 1st morphometric description of marbled murrelets from Desolation Sound and Mussel Inlet. They also have allowed the 1st detailed description of sexual differences in marbled murrelet morphometrics using live birds, and have allowed assessment of the validity of a DFA to determine the sex of marbled murrelets.

TABLE 5. Comparisons of marbled murrelet morphometrics measured in birds captured using different methods and during different sessions (data from 1 observer during 1997; data were insufficient to test females among sessions). There were no statistically significant differences in any of the variables tested.

Variable	Comparison between methods (n: mist-net, night-lighting)	Comparison among sessions (n: am, pm, all night)
Wing chord length:		
Males	$t_{23} = 1.2$ (22, 13)	$F_{2,32} = 1.9$ (10, 12, 13)
Females	$t_4 = 2.2$ (18, 4)	—
Culmen length		
Males	$t_{29} = 0.7$ (22, 13)	$f_{2,32} = 0.9$ (10, 12, 13)
Females	$t_4 = 0.6$ (18, 4)	—
Bill width		
Males	$t_{32} = 2.1$ (22, 13)	$F_{2,32} = 2.2$ (10, 12, 13)
Females	$t_4 = 1.6$ (17, 4)	—
Bill height		
Males	$t_{32} = 1.5$ (22, 13)	$F_{2,32} = 1.7$ (10, 12, 13)
Females	$t_3 = 1.1$ (18, 4)	—
Tarsus length		
Males	$t_{21} = 0.4$ (22, 13)	$F_{2,32} = 1.1$ (10, 12, 13)
Females	$t_{21} = 0.5$ (18, 4)	—

TABLE 6. Significance of variation of morphometrics between male and female marbled murrelets.

Variable	Between sexes				
	Juveniles	1994	1995	1996	1997
Wing chord length	$t_{25} = 0.8$ $P > 0.05$	$t_{65} = 1.9$ $P > 0.05$	$t_{104} = 3.3$ $P < 0.002$	$t_{92} = 1.4$ $P > 0.05$	$t_{302} = 5.5$ $P < 0.0001$
Culmen length	$t_{25} = 0.2$ $P > 0.05$	$t_{64} = 1.6$ $P > 0.05$	$t_{107} = 3.1$ $P < 0.003$	$t_{92} = 1.9$ $P > 0.05$	$t_{302} = 5.5$ $P < 0.0001$
Bill width	$U = 151.0$ $P < 0.05$	$U = 592.5$ $P > 0.05$	$U = 1970$ $P > 0.05$	$U = 1551.0$ $P > 0.05$	$U = 30790.5$ $P > 0.05$
Bill height	$U = 166.5$ $P < 0.05$	$U = 445.0$ $P < 0.05$	$U = 1627.0$ $P > 0.05$	$U = 1609.5$ $P > 0.05$	$U = 28939.5$ $P < 0.05$
Tarsus length	$U = 130.5$ $P < 0.05$	$U = 523.5$ $P > 0.05$	—	$U = 1047.5$ $P > 0.05$	$U = 29213.5$ $P < 0.05$

Inter-observer Effects

Like many large, long-term programs, the study at Desolation Sound requires a number of observers. However, it has resulted in inconsistencies in measurements, even though all observers in the program were trained in measurement techniques. The variety of tests carried out in this study indicated the degree of inter-observer effects. Significant differences in data from different observers within years, the inconsistent differences between sexes each year, inter-annual comparisons from 2 observers, and recapture data that suggested birds had decreased in size, all highlighted the magnitude of the effects.

Percent ME revealed that the least reliable measurement was wing chord length and the most reliable was tarsus length. However, all morphometrics had a high %ME (>10%, as suggested by Lougheed and others 1991). Studies assessing the reliability of morphometrics in passerines found wing length to be the most reliable (Gosler and others 1998), which suggests wings of marbled murrelets may be more difficult to measure accurately than those of many passerines.

Although using data from only 1 observer reduced variability and improved the accuracy of the DFA, it is not feasible for only 1 observer to measure all birds in the Desolation Sound program. The importance of carefully training personnel, cross-checking data among observers, and assessing the degree of inter-observer effects when drawing conclusions about significant differences in morphometrics, cannot be overstated (as suggested by Barrett and others 1989; Dzubin and Cooch 1992).

The standard deviations in measurements of marbled murrelets in our study were smaller than those in a study by Pitoccelli and others (1995) but were larger than those in a study by Sealy (1975). This suggests that the use of 1 measurer results in smaller errors; however, Sealy's (1975) study was conducted in a museum on dead specimens, which may have also allowed more accurate measurements.

Morphometric Comparisons

Adult marbled murrelets were significantly larger than newly fledged juveniles. No differences in morphometrics were found among birds across years, captured at different times of day, or captured using different techniques. Therefore, morphologically distinct groups were not apparent in this study, and no further insight can be provided into why a male-biased sex ratio is found in birds captured by mist-netting but not night-lighting.

Significant differences in culmen length, wing chord length, and tarsus length were found between birds at Desolation Sound and Mussel Inlet, suggesting morphological differences between the populations. Comparisons of murrelets in the current study to those from Langara Island (approximately 600 km N of Desolation Sound) and Alaska (Sealy 1975; Pitocchelli and others 1995) indicated they were similar in size, with some exceptions (Table 7). Birds in the current study had larger culmen lengths and bill heights, but smaller tarsi than those at Langara Island. They also had longer wing chords and culmens than those in Alaska. However, comparisons to the Alaska data set are difficult because the sexes were combined in that study and wing chord length differed between ground- and tree-nesting murrelets.

TABLE 7. Comparison of morphometrics (mm) of marbled murrelets from Desolation Sound, Mussel Inlet (this study), Langara Island (Sealy 1975) and Alaska (Pitocchelli et al. 1995). Mean ± SD, except Langara Island which is mean ± SE. Sample sizes are in parentheses.

Morphometric	Desolation Sound		Mussel Inlet		Langara Island		Alaska (sexes combined)	
	Male	Female	Male	Female	Male	Female	Tree-nesting	Ground-nesting
Wing chord length	132.9 ± 3.8 (315)	131.0 ± 3.2 (201)	133.8 ± 3.9 (59)	132.0 ± 3.0 (60)	134.2 ± 1.2 (25)	132.6 ± 1.8 (23)	128.4 ± 5.9 (140)	132.4 ± 7.0 (14)
Culmen length	17.9 ± 1.0 (316)	17.5 ± 0.9 (203)	17.2 ± 0.9 (58)	17.0 ± 1.0 (59)	15.5 ± 0.3 (36)	15.3 ± 0.4 (32)	160.0 ± 1.6 (134)	15.1 ± 1.4 (12)
Bill height	6.0 ± 0.4 (317)	5.8 ± 0.4 (201)	5.8 ± 0.3 (58)	5.7 ± 0.3 (60)	6.0 ± 0.1 (26)	5.8 ± 0.1 (23)	—	—
Tarsus length	17.9 ± 1.8 (235)	17.4 ± 1.5 (155)	17.7 ± 1.2 (58)	17.8 ± 1.5 (60)	16.2 ± 0.2 (37)	15.9 ± 0.3 (39)	17.9 ± 1.4 (138)	17.4 ± 0.9 (12)

The distribution of marbled murrelets in North America is described as discontinuous with possibly genetically discrete populations and with unknown rates of exchange among them (Ralph and others 1995). While the morphometric data that are provided give an assessment of the discreteness of populations of marbled murrelets, statistical comparisons are not possible until the degree of inter-observer differences among the studies is determined. Until such effects are determined and minimized, conclusions about differences among these populations must be tentative.

Discriminant Function Analysis

The sexual dimorphism found in adult marbled murrelets was small (females were approximately 98% the size of males), but allowed a 65 to 66% success rate in separating sexes using a DFA, with the sex of adults being more accurately identified than the sex of juveniles. Generally the sex of alcids is very difficult to determine in the field due to monomorphic plumage and similarity in body size (Bedard 1985). Reliable determination of the sex of alcids using morphometrics has been achieved with crested auklets (*Aethia cristatella*; 95% accuracy using bill shape, Jones 1993), Cassin's auklets (*Ptychoramphus aleuticus*; 94% and 86% accuracy, Nelson 1981 and H. Knechtel unpubl. data, respectively), ancient murrelets (*Synthliboramphus antiquus*; using bill depth 87% and 70% accuracy, Jones 1985 and Gaston 1992, respectively), and Atlantic puffins (*Fratercula arctica*; 65% accuracy using bill depth and culmen length, Corkhill 1972). There is little sexual dimorphism in common murres (*Uria aalge*) making the use of a DFA impossible (Threlfall and Mahoney 1980), and there also is little apparent dimorphism in razorbills (*Alca torda*), black guillemots (*Cepphus grylle*), and least auklets (*Aethia pusella*) (Gaston and Jones 1998). While the accuracy of the DFA in marbled murrelets is greater than in some other alcids, it has only limited value (particularly given the problem of inter-observer effects), and in order to eliminate errors in the assignment of sex, the molecular technique (Vanderkist and others 1999) must be employed.

This study has determined that there may be some morphological differences between birds from Mussel Inlet and Desolation Sound, and apparent differences between the birds in our study and those in populations in Langara Island and Alaska. The small degree of sexual dimorphism in the species prevents the widespread use of a discriminant formula to identify the sex of individual birds. Future studies of marbled murrelets need to minimize interobserver effects by very careful training of personnel and by cross-checking data from all observers.

ACKNOWLEDGMENTS

We thank the numerous field assistants who have worked on this program. T. D. Williams, S. Courtney and C. Thompson provided comments that improved earlier drafts of the manuscript. Forest Renewal B.C. (FRBC), NSERC, Chair of Wildlife Ecology at Simon Fraser University, Canadian Wildlife Service, MacMillan-Bloedel Ltd, Timber/West Forest Ltd, International Forest Products Ltd, Western Forest Products Ltd, and Pacific Forest Products Ltd. gave generous financial support. Work was conducted under permits BC SCI 97/012A and101201 AQ.

LITERATURE CITED

BAILEY RC, BYRNES J. 1990. A new, old method for assessing measurement error in both univariate and multivariate morphometric studies. Systematic Zoology 39:124–130.

BARRETT RT, PETERZ M, FURNESS RW, DURINCK J. 1989. The variability of biometric measurements. Ringing and Migration 10:13–16.

BARROWCLOUGH G. 1992. Systematics, biodiversity and conservation biology. In: Eldredge N, editor. Systematics, ecology and the biodiversity crisis: New York, NY: Columbia University Press. p 121–143.

BEDARD J. 1985. Evolution and characteristics of the Atlantic Alcidae. In: Nettleship DN, Birkhead TR, editors. The Atlantic Alcidae: London, UK: Academic Press. p 1–51.

BURNS RA, KAISER GW, PRETASH LM. 1995. Use of mist nests to capture marbled murrelets over the water. Northwestern Naturalist 76:106–111.

CARTER HR, STEIN JL. 1995. Molts and plumages in the annual cycle of the marbled murrelet. In: Ralph CJ, Hunt GL, Raphael MG, Piatt JF, editors. Ecology and conservation of the marbled murrelet: General Technical Report PSW-GTR-152, Albany CA: USDA Forest Service, Pacific Southwest Research Station. p 99–109.

CORKHILL P. 1972. Measurements of puffins as a criteria of sex and age. Bird Study 19:193–201.

COUNSILMAN JJ, NEE K, JALIL AK, KENG WL. 1994. Discriminant analysis of morphometric characters as a means of sexing mynas. Journal of Field Ornithology 65:1–7.

DZUBIN A, COOCH E. 1992. Measurement of geese. General field methods. Sacramento, CA: California Waterfowl Association. 20 p.

GASTON AJ. 1992. The ancient murrelet. London, UK: Poyser. 249 p.

GASTON AJ, JONES IL. 1998. The auks. Oxford, UK: Oxford University Press. 349p.

GOSLER AG, GREENWOOD JJD, BAKER JK, DAVIDSON NC. 1998. The field determination of body size and condition in passerines: a report to the British Ringing Committee. Bird Study 45:92–103.

HAMER KC, FURNESS RW. 1991. Sexing great skuas *Catharacta skua* by discriminant analysis using external measurements. Ringing and Migration 12: 16–22.

HEDD A, GALES R, BROTHERS N. 1998. Reliability of morphometric measures for determining the sex of adult and fledgling shy albatrosses, *Diomedea cauta cauta,* in Australia. Wildlife Research 25:69–79.

JONES IL. 1985. Structure and function of vocalizations a related behavior of the Ancient murrelet (*Synthliboramphus antiquus*) [thesis]. Toronto, ON: University of Toronto. 178 p.

JONES IL. 1993. Sexual differences in bill shape and external measurements of crested auklets *Aethia cristatella.* Wilson Bulletin 105:525–529.

KAISER GW, DEROCHER AE, CRAWFORD S, GILL MJ, MANLEY IA. 1995. A capture technique for marbled murrelets in coastal inlets. Journal of Field Ornithology 66(3):321–333.

KOFFIJBERG K, VAN ERDEN MR. 1995. Sexual dimorphism in the cormorant *Phalocrocorax carbo sinensis*: possible implications for differences in structural size. Ardea 83:37–46.

LOUGHEED SC, ARNOLD TW, BAILEY RC. 1991. Measurement error of external and skeletal variables in birds and its effect on principal components. Auk 108:432–436.

NELSON KS. 1981. Sexual measurements of Cassin's auklet. Journal of Field Ornithology 52:233–234.

PHILLIPS RA, FURNESS RW. 1997. Predicting the sex of parasitic jaegers by discriminant analysis. Colonial Waterbirds 20:14–23.

PITOCCHELLI J, PIATT J, CRONIN MA. 1995. Morphological and genetic divergence among Alaskan populations of *Brachyramphus* murrelets. Wilson Bulletin 107:235–250.

PRATER AJ, MARCHANT JH, VUORINEN J. 1977. Guide to the identification and ageing of Holarctic waders. London, UK: British Trust for Ornithology. 168 p.

RALPH CJ, HUNT GL, RAPHAEL G, PIATT JF. 1995. Ecology and conservation of the marbled murrelet in North America: an overview. In Ralph CJ, Hunt GL, Raphael MG Piatt JF, editors. Ecology and conservation of the marbled murrelet. General Technical Report PSW-GTR-152. Albany, CA:

USDA Forest Service, Pacific Southwest Research Station. p 3–22.

SEALY SG. 1975. Aspects of the breeding biology of the marbled murrelet in British Columbia. Bird Banding 46:141–154.

TABACHNIK BG, FIDDELL LS. 1989. Using multivariate statistics. New York: Harper Collins. 746 p.

THRELFALL W, MAHONEY SP. 1980. The use of measurements in sexing common murres from Newfoundland. Wilson Bulletin 92:266–268.

VANDERKIST BA., XUE X-H, GRIFFITHS R, MARTIN K, BEAUCHAMP W, WILLIAMS TD. 1999. Evidence of male-bias in capture samples of marbled murrelets from genetic studies in British Columbia. Condor 101:398–402.

WHITWORTH DL, TAKEKAWA JY, CARTER H, MCIVER RW. 1997. A night-lighting technique for at-sea capture of Xantus' murrelets. Colonial Waterbirds 20:525–531.

Submitted 24 June 2000, accepted 24 January 2001.
Corresponding Editor: C. J. Ralph.