

Hematological and Plasma Biochemical Reference Ranges of Alaskan Seabirds: Their Ecological Significance and Clinical Importance

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Abstract.—Blood was analyzed from 151 pelagic marine birds to establish reference ranges for hematological and plasma biochemical parameters from healthy, wild populations of Pacific seabirds. Of the 13 species examined, 9 were from the Family Alcidae (N = 122 individuals) and the remainder (N = 29) from the Families Phalacrocoracidae, Laridae, and Procellariidae. Three of 8 hematological parameters (total white blood cell count, lymphocyte count and eosinophil count) differed significantly among species, as did 9 of 13 plasma biochemical parameters (alkaline phosphatase, aspartate aminotransferase, creatine kinase, cholesterol, glucose, lactate dehydrogenase, total bilirubin, total protein and field total protein). There were no differences among species for packed cell volume, buffy coat, cell counts of heterophils, monocytes and basophils, or for concentrations of alanine aminotransferase, triglycerides, uric acid and calcium.

Plasma calcium concentration, triglyceride levels and field total protein varied significantly between sexes, with females having higher mean concentrations of all 3 parameters. However, no significant relationships between measures of breeding condition (brood patch size, subcutaneous and mesenteric fat deposits, or ovarian follicle size and ovary weight) and calcium or alkaline phosphatase concentrations in female birds could be identified. Alanine aminotransferase and uric acid were the only analytes which did not differ significantly between species or sexes. Received 25 February 1997, accepted 21 September 1997.

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Traditionally, the health status of wild populations of seabirds has been assessed from measures of population size, reproductive success or annual survival (Ainley and Boekelheide 1990). These methods of assessing population health are both practical and valuable, but they enable biologists to recognize problems only after they have an effect on a large number of individuals. An additional method for determining animal health, which has the advantage of detecting problems prior to impact on colonies or populations, is blood sampling and analysis (Roszkopf *et al.* 1982). Application of this conventional veterinary medical method to wildlife species provides an additional tool for wildlife management.

For some species of animals that receive veterinary care, hematological and clinical pathological (serum or plasma biochemistry) reference ranges exist. However, the majority of data available on wild avian blood

parameters comes from waterfowl, raptors, poultry, or wildlife maintained in zoological or aquaria collections (Lucas and Jamroz 1961, Leonard 1969, Smith and Bush 1978, Roszkopf *et al.* 1982, Franson *et al.* 1982, ISIS 1983, Harrison *et al.* 1986, Allen 1988, Hawkey and Samour 1988, Clubb *et al.* 1991). There is less information available on blood reference ranges for free ranging marine bird species (Kocan 1972, Balasch 1974, Wolf *et al.* 1985, Melrose and Nicol 1992, Rosa *et al.* 1993, Work 1996) and very limited data on Auks (Bradley and Threlfall 1974, Newman and Zinkl 1996).

Blood analyses, in combination with other diagnostic methods, enable veterinarians to assess the health of individuals and to identify organ systems affected by infectious diseases (bacterial, viral, fungal or protozoan), toxins (heavy metals, petroleum products, pesticides), biotoxins (demoic acid, saxitoxin) metabolic diseases or nutritional

deficiencies. Plasma or serum biochemical analyses provide information about internal organs (liver, kidney), electrolytes (sodium, chloride, potassium, calcium phosphate), proteins (immunoglobulins and albumin) and nutritional or metabolic parameters (cholesterol, triglycerides and glucose). Hematological analyses which include white blood cell counts and differential cell counts provide information about the immunological status of an individual and can serve as diagnostic adjuncts in the development of a presumptive or definitive diagnosis (Campbell 1995). Therefore, complete blood analyses from an individual can provide a thorough evaluation of the health status of that animal. Examination of blood from many individuals from the same colony can provide an assessment of colony health.

Of the multiple environmental contaminants marine birds are potentially exposed to, oil spills frequently result in large numbers of birds needing rehabilitation (King *et al.* 1979, Leighton 1982, Piatt and Lensink 1989, Piatt *et al.* 1990, White 1994, Newman 1995). While routine oiled wildlife care is beginning to include complete blood analyses, results are still difficult to interpret because reference range blood parameter data (Newman 1994, Newman and Zinkl 1996) is limited. This makes it difficult to determine: 1) if birds are sick when they arrive at medical facilities; 2) how animals respond to therapy; and 3) when birds are healthy enough to be released. Oiled wildlife rehabilitation has come under increasing scrutiny due to variable post-release survival results from several studies (Anderson *et al.* 1996, Anderson and Newman 1996, Sharp 1996). Some research suggests that oiled and rehabilitated animals reproduce within a year of being oiled and can survive for long periods of time after release (Underhill *et al.* 1994, Williams 1994, Russel, 1996). Other studies suggest that oiled wildlife die soon after release from rehabilitation or do not return to breeding colonies (Anderson *et al.* 1996, Sharp 1996). These conflicting results emphasize the importance of establishing blood reference ranges for marine birds in order to help ensure that rehabilitated and released animals

are healthy, have the best chance for long term survival, and eventually contribute to the population health of that species.

Natural disease and die-off's may also affect large numbers of marine birds, resulting in the need for biomedical care. A recent marine bird die-off incident involved several thousand American White Pelicans (*Pelecanus erythrorhyncho*) and California Brown Pelicans (*Pelecanus occidentalis californicus* (Rocke 1997). Due to their endangered status, hundreds of sick California Brown Pelicans were medically treated and released back into the wild after a botulism (*Clostridium botulinum*) outbreak at the Salton Sea, California (Bloom 1997). Although many birds were treated and released, the physiological condition of these animals was not well known upon release making the long term prognosis for these animals difficult to evaluate.

As the health of marine bird populations continues to be compromised by habitat loss, colony disturbance, decreasing prey availability and environmental pollutants; and as isolated colonies become more important for preserving genetic diversity, the need for better medical care of diseased or contaminated birds becomes increasingly important. Currently, Marbled Murrelets (*Brachramphus marmoratus*) are the only endangered Alcid, however, population declines on the west coast continue to be documented annually for many Alcids (Carter *et al.* 1995) emphasizing the need for baseline health information which will facilitate better care for these species. The object of this paper is to establish baseline hematological and plasma biochemical reference ranges for wild marine birds. With this data, resource managers and agencies will be able to better manage marine bird resources and address future health problems.

STUDY REGION AND METHODS

Blood samples from 151 healthy seabirds were collected at the Shumigan Islands (55°05'N, 159°32'W), Alaska between 8 June, 1990 and 17 June, 1990 as part of coordinated studies on seabird feeding ecology and plastics consumption by the U.S. Fish and Wildlife Service (Robards *et al.*, 1995). This site was chosen because there has been no known major environmental contamination of this ecosystem, there were healthy breeding seabird colonies nearby, and therefore, it is assumed

that blood samples are from healthy, uncontaminated birds. Of the 151 blood samples examined, 122 were from birds of the Family Alcidae and included: Ancient Murrelets (ANMU), Cassin's Auklets (CAAU), Crested Auklets (GRAU), Parakeet Auklets (PAAU), Marbled Murrelets (MAMU), Pigeon Guillemots (PIGU), Common Murres (COMU), Horned Puffins (HOPU) and Tufted Puffins (TUPU). Species sampled which are not Alcids included: Northern Fulmars (NOFU), Glaucous-winged Gulls (GWGU), Black-legged Kittiwakes (BLKI), and Pelagic Cormorants (PECO) (Table 1).

Adult birds were collected by gunshot from a Zodiac™ as they flew over head en route to or from the Shumigan Islands. Within 3 minutes after being sacrificed, blood samples were drawn via intracardiac puncture using 20, 22, or 23 gauge needles and 3, 6 or 12 cc syringes. Blood samples were immediately transferred into Vacutainer PST Plasma Separation Tubes™ (Becton Dickson and Co., Cockeysville, Maryland, USA) and Monoject EDTA Tubes™ (Sherwood Medical, St. Louis, Missouri, USA). Plasma samples were refrigerated 1 to 7 hours in a sea water bath at temperatures $\leq 10^{\circ}\text{C}$, then centrifuged for 5 minutes at 3500 rpm using a generator-powered Triac Centrifuge™ (Clay Adams, Sparks, Maryland, USA) in order to separate the plasma from the cellular fraction. Disposable polyethylene pipettes were used to pipette plasma into plastic 1.5 ml microcuvials (Out Patient Services, Petaluma, California, USA) and stored in liquid nitrogen until analyses could be performed at the laboratory in Anchorage, Alaska.

Whole blood samples in EDTA Tubes™ were refrigerated in the sea water bath from 1 to 4 hours before blood smears were made. Slides were air dried, labeled and stored in slide boxes until staining at the lab in Anchorage. Concurrently, Heparinized Pre-Cal Microhematocrit Tubes™ (Clay Adams, Parsippany, New Jersey, USA) were filled and clay capped in order to perform packed cell volume (PCV), buffy coat (BC) and field total protein (field TP) measurements. Microhematocrit tubes were centrifuged for 3 minutes at 10,400 rpm. PCV and BC were determined by measuring the percent of red blood cells and buffy coat respectively, in the whole blood sample using a Hematocrit Reading Scale™ (Sherwood Medical, St. Louis, Missouri, USA). Field TP was measured on plasma samples obtained

from the spun microhematocrit tubes using a hand held temperature compensated Schuco Clinical Refractometer™ (American Calduceus Industries Inc., Carle Place, New York, USA).

At the field site, gross necropsies and morphological measurements were performed (body weight, culmen, tarsus, wing cord, body fat and brood patch size). Brood patches were scaled from 0 to 3, with 0 being no brood patch development and 3 being a completely developed (roughly 4 cm \times 4 cm), vascularized brood patch. Body condition was estimated by direct visualization of subcutaneous and visceral fat stores. Fat stores were categorized using a scale of 1 to 3, representing light, moderate and large fat deposits. These measurements were performed by the same individuals to standardize results. For inter-species comparison of gonadal development, gonad length and width (in millimeters) were converted into an index by multiplying the gonad sizes (length and width) and dividing by the weight of the bird. This produced a number by which the sexual activity of the bird was estimated.

At the laboratory in Anchorage, frozen plasma was thawed and analyses were performed using an Abbott Visions Analyzer™ (Abbott Laboratories, Abbott Park, Illinois, USA) according to standard operating procedures. When necessary, dilutions of plasma were made with Abbott Laboratories 0.9% NaCl USP™ (Abbott Laboratories, Abbott Park, Illinois, USA) using a Kodak Ektachem DT Pipette™ (Kodak Company, Rochester, New York, USA). Plasma concentrations or activities of the following analytes were measured through enzymatic rate reactions: glucose; uric acid (UA); cholesterol; triglycerides; total bilirubin (TBili); calcium (Ca); alkaline phosphatase (Alk Phos); aspartate aminotransferase (AST)/SGOT; alanine aminotransferase (ALT)/SGPT; lactate dehydrogenase (LDH); creatine kinase (CK) and total protein (TP).

Blood smears were stained using Wright's-Giemsa Stain (Dein 1982). All white blood cell (WBC) estimates were performed by the same 2 technicians, at a location on the slide where the cells were 1 layer thick, adjacent to one another (membranes touching), evenly distributed, and showed no signs of morphological changes. WBC estimates were obtained by using a 40 \times objective lens, counting the number of white blood cells in 10

Table 1. Species and number of individuals collected from the Shumigan Islands, Alaska between 8-17 June, 1990.

Common name	Family	Taxonomic classification	N
Ancient Murrelet	Alcidae	<i>Synthliboramphus antiquus</i>	10
Black-legged Kittiwake	Laridae	<i>Rissa tridactyla</i>	10
Cassin's Auklet	Alcidae	<i>Ptychoramphus marmoratus</i>	4
Common Murre	Alcidae	<i>Uria aalge</i>	6
Crested Auklet	Alcidae	<i>Aethia cristatella</i>	11
Glaucous-winged Gull	Laridae	<i>Larus glaucescens</i>	9
Horned Puffin	Alcidae	<i>Fratercula corniculata</i>	17
Marbled Murrelet	Alcidae	<i>Brachramphus marmoratus</i>	11
Northern Fulmar	Procellariidae	<i>Fulmarus glacialis</i>	5
Parakeet Auklet	Alcidae	<i>Cyclorhynchus psittacula</i>	26
Pelagic Cormorant	Phalacrocoracidae	<i>Phalacrocorax pelagicus</i>	5
Pigeon Guillemot	Alcidae	<i>Cephus columba</i>	7
Tufted Puffin	Alcidae	<i>Lunda cirrhata</i>	30
		Total	151

fields, taking the average, and then multiplying the number of cells by 2,000 (Consolidated Veterinary Diagnostics 1995, Gaunt *et al.* 1996). If the PCV was less than 40%, and a PCV reference range exists for that species (Balasch *et al.* 1974, Newman and Zinkl 1996), a corrected WBC estimate (WBC \times mean recorded PCV / mean reference range PCV) is reported (Consolidated Veterinary Diagnostics 1995). Differential white blood cell counts were performed by counting the percentage of heterophils, lymphocytes, monocytes, eosinophils and basophils in 100 white blood cells using a 40 \times objective lens. The absolute cell counts for each of these cell types was calculated by multiplying the percentage of the particular cell type by the overall WBC estimate.

Descriptive statistics were performed using BMDP Statistical Software (BMDP, Los Angeles, California, USA) for all analytes. Kruskal-Wallis One Way ANOVA was performed to identify differences in analytes between species. ANOVA, Bonferroni Test, and Tukey's Studentized Range Method were used to examine the differences in blood parameters both between the sexes and among reproductive parameters in females (brood patch size, subcutaneous and mesenteric fat deposits, ovarian follicle size and ovary weight).

RESULTS

Blood was analyzed from 13 species with variable sample sizes (N = 4 - 30) for each species (Table 1). Blood samples were ana-

lyzed for all analytes if adequate plasma volume and slides were available. Mean hematological and plasma biochemical results are presented for each species examined (Tables 2-6). White blood cell estimates and cell counts are reported as cells per microliter. For comparisons between male and female birds, sample sizes were greater than 100 with the exceptions of AST, LDH, and CK where sample sizes were 62, 82, and 87 due to limited plasma volume.

Overall, 9 of the 13 clinical pathology parameters (Alk Phos, AST, CK, cholesterol, glucose, LDH, TBili, TP and field TP) differed significantly ($p < 0.05$) between species. However, specific species differences were detected in only 5 of 13 parameters (Alk Phos, CK, glucose, LDH, and TP) by pairwise comparisons (Table 7). Triglycerides, ALT, UA and calcium concentrations did not differ between species. Of the 8 hematology parameters measured, 3 varied significantly among species overall (WBC

Table 2. Hematological and plasma biochemical reference ranges for seabirds.

Hematology	Ancient Murrelet			Black-legged Kittiwake			Cassin's Auklet		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
WHITE BLOOD CELL ESTIMATE	9	4083	1920	10	4180	1701	1	9200*	—
HETEROPHILS	9	21	18	10	30	14	1	80	—
LYMPHOCYTES	9	69	18	10	62	14	1	16	—
MONOCYTES	9	2	2	10	2	2	1	0	—
EOSINOPHILS	8	9	2	10	5	4	1	4	—
BASOPHILS	9	1	1	10	0	1	1	0	—
PACKED CELL VOLUME (%)	10	40	9	10	41	7	4	34	9
BUFFY COAT (%)	10	0.7	0.5	10	0.6	0.4	4	1.3	0.5
FIELD TOTAL PROTEIN (gm/dl)	9	5.2	0.6	10	4.7	0.7	4	5.2	1.3
Plasma Biochemistry	N	Mean	SD	N	Mean	SD	N	Mean	SD
GLUCOSE (mg/dl)	7	271	75	9	331	60	2	245	20
URIC ACID (mg/dl)	4	28	15	8	19	6	2	27	7
CHOLESTEROL (mg/dl)	7	300	71	9	387	94	3	253	25
TRIGLYCERIDE (mg/dl)	8	318	172	9	273	380	2	162	61
ALK PHOS (IU/L)	4	62	35	9	123	96	1	254	—
AST/SGOT (IU/L)	3	806	403	6	690	345	1	387	—
ALT/SGPT (IU/L)	6	160	60	9	138	105	2	601	653
LACTATE DEHYDROGENASE (IU/L)	5	2920	1275	7	715	384	1	674	—
TOTAL BILIRUBIN (mg/dl)	7	1.5	0.8	9	1.5	0.7	2	0.3	0.1
CALCIUM (MEQ/L)	9	9.3	1.0	10	9.8	2.9	3	7.5	1.7
CK (IU/L)	6	3331	2854	5	770	811	1	1417	—
TOTAL PROTEIN (gm/dl)	7	4.5	0.6	9	3.8	0.4	2	3.7	0.4

*The corrected WBC estimate based on a reported PCV reference range (PCV = 50) = 6256.

Table 3. Hematological and plasma biochemical reference ranges for seabirds.

Hematology	Common Murre			Crested Auklet			Glaucous-winged Gull		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
WHITE BLOOD CELL ESTIMATE	3	9350*	1348	7	2529	1122	8	5077**	4470
HETEROPHILS	3	31	28	7	22	23	8	53	20
LYMPHOCYTES	3	51	21	7	70	20	8	43	16
MONOCYTES	3	2	2	7	4	2	8	1	1
EOSINOPHILS	3	16	6	7	4	3	8	3	4
BASOPHILS	3	0	0	7	1	1	8	0	0
PACKED CELL VOLUME (%)	6	39	4	11	40	6	9	38	8
BUFFY COAT (%)	6	0.7	0.8	11	1.1	1.0	9	0.7	0.3
FIELD TOTAL PROTEIN (gm/dl)	6	4.3	0.6	11	5.1	1.1	9	4.0	0.8
Plasma Biochemistry	N	Mean	SD	N	Mean	SD	N	Mean	SD
GLUCOSE (mg/dl)	5	313	119	4	238	77	9	320	60
URIC ACID (mg/dl)	6	19	16	6	17	4	9	28	11
CHOLESTEROL (mg/dl)	5	376	244	3	221	91	9	268	92
TRIGLYCERIDE (mg/dl)	6	211	162	6	158	45	9	163	178
ALK PHOS (IU/L)	5	69	21	4	131	79	9	252	342
AST/SGOT (IU/L)	4	164	83	2	296	131	7	468	298
ALT/SGPT (IU/L)	5	85	31	3	138	51	9	122	5901
LACTATE DEHYDROGENASE (IU/L)	5	1304	345	3	1055	799	8	1010	877
TOTAL BILIRUBIN (mg/dl)	5	1.2	1.1	4	1.8	1.4	9	0.7	0.5
CALCIUM (MEQ/L)	6	10.5	1.2	8	8.6	2.0	9	9.6	2.3
CK (IU/L)	5	624	379	3	584	263	8	1629	1468
TOTAL PROTEIN (gm/dl)	5	5.7	3.0	4	3.2	0.5	9	3.4	0.4

*The corrected WBC estimate based on a reported PCV reference range (PCV = 50) = 7293.

**The corrected WBC estimate based on a reported PCV reference range (PCV = 43) = 4487.

count, lymphocyte count and eosinophil count). From pairwise analyses, only WBC and the eosinophil count had detectable species differences (Table 8). The PCV, BC, heterophil count, monocyte count, and basophil count did not vary significantly between species.

Parametric analyses (ANOVA, Bonferroni Test, and Tukey's Studentized Range Method) were used to examine the differences in clinical pathology parameters both between the sexes and among reproductive based parameters in females. Mean plasma concentrations of calcium, triglycerides and field TP varied significantly ($p < 0.05$) between sexes, with female birds having higher mean concentrations for all 3 parameters (Table 9). No statistically significant correlations could be identified between measures of breeding condition (brood patch size, subcutaneous and mesenteric fat deposits, ovarian follicle size and ovary weight) and calcium or alkaline phosphatase concentrations in female birds.

DISCUSSION

Statistically significant differences between species were identified for 7 of 21 blood parameters measured (Table 7 and 8). Most differences detected for plasma biochemistry parameters also represented differences across taxonomic families of bird species. For example, Alk Phos activities of Alcids (ANMU, HOPU and TUPU) were lower than PECO (Phalacrocoracidae) activities. Black-legged Kittiwake (Laridae) CK activity was lower than MAMU (Alcidae) CK activity. The MAMU (Alcidae) glucose concentration was lower than BLKI (Laridae) and PECO (Phalacrocoracidae) glucose levels. Finally, TP concentrations of GWGU were lower than TP levels in MAMU and TUPU samples. Lactate dehydrogenase is the only analyte with activities which differed within a taxonomic family and between taxonomic families. LDH levels were lower in BLKI, HOPU and TUPU (Laridae and Alcidae) versus ANMU (Alcidae).

Table 4. Hematological and plasma biochemical reference ranges for seabirds.

Hematology	Horned Puffin			Marbled Murrelet			Northern Fulmar		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
WHITE BLOOD CELL ESTIMATE	18	4333	1830	11	5682	1999	5	3360*	921
HETEROPHILS	18	32	27	11	26	21	5	29	16
LYMPHOCYTES	18	57	19	11	63	14	5	56	20
MONOCYTES	18	4	5	11	1	1	5	2	2
EOSINOPHILS	18	7	11	11	9	8	5	13	10
BASOPHILS	18	1	1	11	2	3	5	0	1
PACKED CELL VOLUME (%)	17	44	8	11	41	6	5	32	8
BUFFY COAT (%)	17	0.5	0.4	11	0.8	0.6	5	0.6	0.4
FIELD TOTAL PROTEIN (gm/dl)	17	5.8	2.4	11	6.2	2.1	5	4.7	0.6
Plasma Biochemistry	N	Mean	SD	N	Mean	SD	N	Mean	SD
GLUCOSE (mg/dl)	14	318	55	8	228	61	5	226	42
URIC ACID (mg/dl)	13	30	15	9	30	12	5	6	7
CHOLESTEROL (mg/dl)	15	323	77	6	246	36	5	363	53
TRIGLYCERIDE (mg/dl)	14	472	650	9	284	223	5	144	48
ALK PHOS (IU/L)	13	109	98	7	129	112	5	219	218
AST/SGOT (IU/L)	10	183	126	1	46	—	4	414	214
ALT/SGPT (IU/L)	14	165	111	6	102	71	5	28	8
LACTATE DEHYDROGENASE (IU/L)	14	886	688	5	1342	720	4	1432	951
TOTAL BILIRUBIN (mg/dl)	15	1.5	1.1	7	1.2	0.9	5	0.5	0.3
CALCIUM (MEQ/L)	15	14.2	7.6	8	10.1	3.0	5	10.6	2.0
CK (IU/L)	13	1613	1102	6	4262	893	4	2554	1235.5
TOTAL PROTEIN (gm/dl)	14	4.3	1.0	9	4.9	1.0	5	3.7	1.0

*An uncorrected WBC estimate is reported despite a PCV \leq 40%. This is done because no reference range PCV is available for this species.

Although the clinical relevance of these differences is not clear, there may be evolutionary and ecological implications. Since blood parameters are indicators of internal organ health and systemic homeostasis, some differences in blood parameters across taxonomic families might be expected because morphological adaptations which partly define taxonomic classifications facilitate the use of different habitats and ecological niches for species within different taxonomic groups. However, avian species within the same taxonomic groups, which share similarities in morphological traits, natural histories, pelagic habitats, feeding habits and reproductive habits would be expected to have fewer significant differences in blood parameter concentrations. This latter hypothesis is supported by our data but a larger sample size is desirable to confirm these differences.

It is important to recognize that many environmental variables can potentially influence blood reference ranges including; the

season, photoperiod, geographical location from which birds are sampled, oceanographic conditions and food availability. Additionally, variability in blood cell numbers, enzyme activities and electrolyte concentrations can occur due to the age and sex of individuals, diurnal cycles, body condition, stage of the breeding cycle during which animals are sampled (Martin *et al.* 1975), and the capture technique used. For example, birds exhibit different levels of muscle exertion in association with capture techniques or handling methods used (Bollinger *et al.* 1989). Prolonged handling and struggling, coupled with anaerobic glycolysis can lead to a potentially life threatening syndrome, capture myopathy. This in turn, can result in acidosis, increased CK, AST and LDH activity, elevated potassium levels, and decreased glucose concentrations (Wobeser 1981, Franson *et al.* 1982, Allen 1988).

Interestingly, MAMU in this study had significantly higher baseline CK activities

Table 5. Hematological and plasma biochemical reference ranges for seabirds.

	Parakeet Auklet			Pelagic Cormorant			Pigeon Guillemot		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Hematology									
WHITE BLOOD CELL ESTIMATE	21	4988	2659	3	3133*	1848	9	4039	2265
HETEROPHILS	21	37	21	3	61	13	9	47	13
LYMPHOCYTES	21	59	21	3	27	5	9	47	14
MONOCYTES	21	2	2	3	2	4	9	1	2
EOSINOPHILS	21	2	4	3	8	2	9	5	4
BASOPHILS	21	0	0	3	2	3	9	0	0
PACKED CELL VOLUME (%)	24	42	11	5	30	12	7	47	7
BUFFY COAT (%)	24	0.6	0.8	5	0.3	0.2	7	0.6	0.4
FIELD TOTAL PROTEIN (gm/dl)	24	5.0	1.3	5	4.7	1.6	7	4.4	1.1
Plasma Biochemistry									
GLUCOSE (mg/dl)	18	298	50	5	224	23	7	323	58
URIC ACID (mg/dl)	22	14	10	5	30	6	7	24	12
CHOLESTEROL (mg/dl)	19	406	140	5	272	72	7	293	65
TRIGLYCERIDE (mg/dl)	21	159	181	4	228	177	7	391	581
ALK PHOS (IU/L)	19	128	113	5	1337	540	7	150	92
AST/SGOT (IU/L)	9	776	581	3	587	339	3	470	329
ALT/SGPT (IU/L)	14	233	157	5	214	73	7	177	81
LACTATE DEHYDROGENASE (IU/L)	12	1100	585	4	1345	218	3	1062	296
TOTAL BILIRUBIN (mg/dl)	17	1.1	0.8	5	1.8	2.4	7	2.4	1.5
CALCIUM (MEQ/L)	26	9.7	3.6	5	10.1	1.9	7	12.2	8.7
CK (IU/L)	14	2392	2455	5	3799	3956	6	2115	2703
TOTAL PROTEIN (gm/dl)	18	4.2	0.8	5	3.6	0.5	7	4.0	0.5

*The corrected WBC estimate based on a reported PCV reference range (PCV = 43.5) = 2161.

and significantly lower glucose levels than other species. The higher CK activity could indicate that murrelets have higher baseline activities of this enzyme compared to other species. Because of the threatened status of MAMU in California, Oregon, Washington, and British Columbia, intensive management programs have been instituted which include handling MAMU for banding purposes, morphometrics, telemetry and captive management. Future research should try to evaluate blood stress and muscle enzyme activity levels associated with capture and handling techniques used. Results should be interpreted in light of the higher baseline CK activity found for MAMU versus other seabird species. This will help ensure that further endangered species research does not unduly impact murrelets.

Blood cholesterol and triglyceride concentrations in all species are regulated by dietary intake and lipid metabolism (Duncan *et al.* 1994). In this study, an overall difference was noted among species for cholesterol,

but no paired species specific differences could be identified for either parameter. Multiple blood analytes (glucose, proteins, vitamins and minerals) including cholesterol and triglyceride levels serve as indicators of the nutritional status of wild marine birds. Since nutritional deficiencies are known to decrease immunocompetence and result in increased incidence of diseases in other species (Puls 1994), poor nutritional status in marine birds might make wild birds more susceptible to naturally occurring organisms which are routinely tolerated by healthy, non-compromised animals. In addition, stress associated with captivity may contribute to immunosuppression, further compromising a marine birds' ability to remain healthy for long periods of time in captivity.

Alaskan marine birds evaluated in this study have significantly higher cholesterol concentrations when compared to Psittacines (Halliwell 1981). Elevated cholesterol values can be caused by renal, hepatic or endocrine disease (Duncan *et al.* 1994). At

Table 6. Hematological and plasma biochemical reference ranges for seabirds.

Hematology	Tufted Puffin		
	N	Mean	SD
WHITE BLOOD CELL ESTIMATE	30	3978	1867
HETEROPHILS	30	37	19
LYMPHOCYTES	30	57	18
MONOCYTES	30	3	6
EOSINOPHILS	30	4	8
BASOPHILS	30	1	2
PACKED CELL VOLUME (%)	30	41	7
BUFFY COAT (%)	30	0.7	0.6
FIELD TOTAL PROTEIN (gm/dl)	30	5.3	1.4
Plasma Biochemistry	N	Mean	SD
GLUCOSE (mg/dl)	24	279	45
URIC ACID (mg/dl)	22	21	14
CHOLESTEROL (mg/dl)	22	347	58
TRIGLYCERIDE (mg/dl)	22	250	348
ALK PHOS (IU/L)	19	74	61
AST/SGOT (IU/L)	13	437	291
ALT/SGPT (IU/L)	20	133	151
LACTATE DEHYDROGENASE (IU/L)	15	952	403
TOTAL BILIRUBIN (mg/dl)	23	2.1	1.3
CALCIUM (MEQ/L)	27	11.7	5.0
CK (IU/L)	17	2586	2486
TOTAL PROTEIN (gm/dl)	24	4.7	0.8

necropsy, no gross lesions were noted in the liver or kidneys of these birds and no blood biochemical changes suggested pathological changes in organs. A more likely explanation for higher cholesterol concentrations in seabirds is the high fat content of the fish consumed by these species. Their diets commonly include sandlance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), wall-eye pollock (*Theragra chalcogramma*) and euphausiids, most commonly *Thysanoessa inermis* (Piatt, unpubl. data).

Avian species excrete excess nitrogen-containing compounds from protein metabolism in the form of uric acid (King and McLelland 1984). Although the blood nitrogen concentrations can be affected by metabolic needs and dietary intake, the kidneys closely regulate the uric acid concentration in avian blood (Campbell 1986). Uric acid does not increase significantly secondary to dehydration (Lumeij 1987) and for this reason, uric acid concentration is the most reliable blood parameter in avian species to assess renal function. The mean uric acid

concentrations for many of the pelagic marine birds investigated were between 20 and 30 mg dl⁻¹ which is compatible with other wild fish eating species (Newman and Zinkl, 1996), but higher than reported values for other avian species (3 to 10 mg dl⁻¹) (Campbell 1986). From an evolutionary standpoint, marine birds are well adapted for concentrating urates in order to filter fresh water from sea water they ingest. Coupled with high-protein fish and invertebrate diets, these factors may contribute to the high uric acid concentrations we observed in pelagic marine birds.

For all seabird species combined, males and females had statistically different ($p < 0.05$) mean concentrations of calcium, triglyceride and field TP (Table 9). Of these parameters, calcium is the only analyte documented to fluctuate in females with reproductive cycles and egg laying (Ivins *et al.* 1978). Despite the difference in calcium concentrations between males and females, no statistically significant correlations were found between measures of breeding condi-

Table 7. Mean and standard deviation for plasma biochemical parameters of Alaskan seabirds for which significant species differences exist.

Species	Alkaline Phosphate (U/I)	Creatine Kinase (U/I)	Glucose (mg/dl)	Lactate Dehydrogenase (U/I)	Total Protein (g/dl)
Ancient Murrelet	62 ± 35a	3331 ± 2854ab	271 ± 75ab	2920 ± 1275a	4.5 ± 0.6ab
Black-legged Kittiwake	123 ± 96ab	770 ± 811a	331 ± 60a	715 ± 384b	3.8 ± 0.4ab
Cassin's Auklet	254 ± 0.0ab	1417 ± 0.0ab	245 ± 20ab	674 ± 0.0ab	3.7 ± 0.4ab
Common Murre	69 ± 21ab	624 ± 379a	313 ± 119ab	1304 ± 345ab	5.7 ± 3.0ab
Crested Auklet	131 ± 79ab	584 ± 263ab	238 ± 77ab	1055 ± 799ab	3.2 ± 0.5ab
Glaucous-winged Gull	252 ± 342ab	1629 ± 1468ab	320 ± 60ab	1010 ± 877ab	3.4 ± 0.4a
Horned Puffin	109 ± 98a	1613 ± 1102ab	317 ± 55ab	886 ± 688b	4.3 ± 1.0ab
Marbled Murrelet	129 ± 112ab	4262 ± 893b	228 ± 61b	1342 ± 720ab	4.9 ± 1.0b
Northern Fulmar	219 ± 218ab	2554 ± 1236ab	226 ± 42ab	1432 ± 951ab	3.7 ± 1.0ab
Parakeet Auklet	128 ± 113ab	2392 ± 2455ab	296 ± 50ab	1100 ± 585ab	4.2 ± 0.8ab
Pelagic Cormorant	1337 ± 540b	3799 ± 3096ab	224 ± 23b	1345 ± 218ab	3.6 ± 0.5ab
Pigeon Guillemot	150 ± 92ab	2115 ± 2703ab	323 ± 58ab	1062 ± 296ab	4.0 ± 0.5ab
Tufted Puffin	74 ± 61a	2586 ± 2486ab	279 ± 45ab	952 ± 403b	4.7 ± 0.8b

Mean concentrations with letters in common are not significantly different with a level of significance of 5% over all comparisons.

Table 8. Mean and standard deviation for hematological parameters of Alaskan seabirds for which significant species differences were detected.

Species	WBC (cells/ μ l)	Eosinphils (cells/ μ l)
Ancient Murrelets	4083 \pm 1920abc	2.7 \pm 2.4ab
Black-legged Kittiwake	4180 \pm 1701abc	5.1 \pm 4.3ab
Cassin's Auklet*	9200 \pm 0.0ac	4.0 \pm 0.0ab
Common Murre*	9350 \pm 1348b	15.7 \pm 5.7a
Crested Auklet	2529 \pm 1122ac	3.6 \pm 3.0ab
Glaucous-winged Gull*	5077 \pm 4470abc	3.4 \pm 3.6ab
Horned Puffin	4333 \pm 1830abc	7.2 \pm 10.6ab
Marbled Murrelet	5682 \pm 1999abc	8.6 \pm 7.5ab
Northern Fulmar*	3360 \pm 921abc	12.8 \pm 10.1ab
Parakeet Auklet	4988 \pm 2659abc	2.2 \pm 3.8b
Pelagic Cormorant*	3133 \pm 1848abc	7.7 \pm 2.1ab
Pigeon Guillemot	4039 \pm 2265abc	4.9 \pm 3.5ab
Tufted Puffin	3978 \pm 1867ac	4.2 \pm 7.5b

*Uncorrected WBC estimate presented.

Mean concentrations with letters in common are not significantly different with a level of significance of 5% over all comparisons.

tion (presence of a brood patch, subcutaneous and mesenteric fat deposits, ovarian follicle size and ovary weight) and calcium levels. However, a trend between calcium concentrations and body fat levels in females was noticed. Birds with slight amounts of subcutaneous and mesenteric fat had lower calcium concentrations than birds with large fat volumes. It is known that female birds undergo significant metabolic activity and energy expenditure associated with egg production and follicular activity (Bell 1960). This may explain why sampling birds post-breeding resulted in a trend between low body-fat levels and low calcium concentrations. There is abundant information on calcium concentrations in female birds during pre-breeding and laying (Ghebremeskel *et al.* 1991), but little is known about wild female marine birds post egg-laying.

Alkaline phosphatase activities have been documented to increase with egg-laying when calcium is replaced back into bones af-

ter resorption for egg production (Bell 1960). However, no enzyme activity difference was observed between males and females in this study. Furthermore, no significant correlations between alkaline phosphatase activity and brood patch size, ovary size or mesenteric and subcutaneous fat were detected. A general trend of decreasing mean alkaline phosphatase activity (330.09 mg dl⁻¹ to 169.96 mg dl⁻¹ to 139.44 mg dl⁻¹) was observed in female birds as brood patch size increased. Further research on the avian regulation of plasma calcium, alkaline phosphatase and reproductive hormones throughout the breeding season is needed to fully appreciate this complex biological activity.

With the exception of COMU, mean field TP measurements performed on plasma using a refractometer were higher than mean total protein measurements performed on plasma using a colorimetric biuret method. It is unclear why this finding

Table 9. Analytes for which significant differences between males and females were detected.

Analyte	Males		Females	
	N	mean	N	mean
Calcium (MEQ/L)	55	9.9 \pm 3.1	53	13.0 \pm 6.6
Triglycerides (mg/dl)	61	220 \pm 239	53	370 \pm 481
Field total protein (gm/dl)	81	4.8 \pm 0.9	70	5.6 \pm 1.9

was not consistent for all species in this study. The biuret method is very specific for plasma protein measurements whereas the refractometer will measure any component in the blood which refracts light. Clinical analytes such as glucose, immunoglobulins or uric acid may elevate the refractometer reading. Another explanation for this finding may be the high carotene concentrations in fish diets of these pelagic birds which can cause non-hemolyzed plasma or serum to be discolored orange or red.

In this study, white blood cell estimates for most pelagic marine birds were between 3,000 and 6,000 cells. From a clinical perspective, these white blood cell counts can be equated with healthy birds for which there were no gross pathological lesions suggestive of an inflammatory response, infection, parasitism or stress response. These counts represent baseline cellular immunocompetence of marine birds and they correspond to the lower ends of reference ranges established for free ranging Alcidae and Laridae in California, Oregon and Washington (Newman and Zinkl, 1996, Newman 1996). Performing white cell estimates from blood smears is less accurate than performing actual white blood cell counts using a hemocytometer and Natt-Herrick's Solution or Eosinophil Unopette™ system (Campbell 1986). However, white blood cell estimates are routinely utilized by both veterinary school laboratories and private laboratories (Gaunt *et al.* 1996) when fresh blood samples are unavailable.

Statistically significant differences in white blood cell counts were identified for CAAU, COMU, CRAU and TUPU. The results from COMU and CAAU come from small sample sizes, however, and this may have biased the results (Table 8). Eosinophil counts showed detectable species differences, but counts may vary in wild avian populations with levels of parasitism (Duncan *et al.* 1994) within a colony, or within a geographical region. Additional geographical comparisons of pelagic marine birds and their hematological parameters needs to be performed to fully appreciate the interaction between ecosystems and blood parameters of wild avian species.

This study is the first attempt to establish hematological and plasma biochemical reference ranges for free-ranging Alaskan seabird species. While we acknowledge that sample sizes for some of the species are relatively small, the reference ranges reported here represent basic health information from which future comparisons and interpretations can be made. Larger sample sizes will help explain the variability in reference range values we observed and help elucidate ecological factors which may influence blood cell counts, enzyme activities and electrolyte concentrations. Once reference ranges are established for free ranging pelagic bird species, clinical evaluations and care for these species will improve and aid in future conservation efforts.

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REFERENCES CITED

- Ainley, D. G. and R. J. Boekelheide (Eds.). 1990. Seabirds of the Farallon Islands: Ecology, dynamics, and structure of an upwelling-system community. Stanford University Press, Stanford, California.
- Allen, J. L. 1988. An overview of avian serum chemical profiles. Pages 143-159 in *Exotic animals* (E. R. Jacobson and G. V. Kollias, Eds.). Churchill Livingstone, New York.
- Anderson, D. W. and S. H. Newman. 1996. Efficacy of treatment for oiled birds (Coot Rehabilitation Project) in Preliminary report to California Department of Fish and Game, Office of Oil Spill Prevention and Response.
- Anderson, D. F., F. Gress and D. M. Fry. 1996. Survival and dispersal of oiled Brown Pelicans after rehabili-

- tation and release. *Marine Pollution Bulletin* 32(10): 711-718.
- Balasz, J., J. Palomeque, L. Palacios, S. Musquera and M. Jimenez. 1974. Hematological values of some great flying and aquatic-diving birds. *Journal of Comparative Biochemistry and Physiology* 49A: 137-145.
- Bell, D. J. 1960. Tissue components of the domestic fowl, plasma alkaline phosphatase activity. *Biochemistry Journal* 75: 224.
- Bloom, E. C. 1997. The Salton Sea experience: Coordination meeting between the California Department of Fish and Game and the U.S. Fish and Wildlife Service, Sacramento, California. August 19, 1997.
- Bollinger, T., G. Wobeser, R. G. Clark, D. J. Nieman and J. R. Smith. 1989. Concentration of creatine kinase and aspartate aminotransferase in the blood of wild Mallards following capture by three methods for banding. *Journal of Wildlife Disease* 25 (2): 225-231.
- Bradley, W. L. and W. Threlfall. 1974. Blood cell indices of five species of auk (Alcidae) from Newfoundland, Canada. *Journal of the Zoological Society of London* 174: 377-385.
- Campbell, T. W. 1986. Avian clinical hematology and blood chemistry. Pages 264-276 in *Veterinary clinical pathology* (E. H. Coles, Ed.). W. B. Saunders Company, Philadelphia, Pennsylvania.
- Campbell, T. W. (Ed.). 1995. Avian hematology. Pages 1-19 in *Avian hematology and cytology*, 2nd edition. Iowa State University Press, Ames, Iowa.
- Carter, H. R., D. F. Gilmer, J. E. Takekawa, R. W. Lowe and U. W. Wilson. 1995. Breeding seabirds in California, Oregon and Washington. Pages 43-49 in *Our living resources: A report to the nation on the distribution, abundance and health of U.S. plants, animals and ecosystems* (E. T. LaRowe, G. F. Farrif, C. E. Puckett, P. D. Duran and M. J. Mac, Eds.), U.S. Department of the Interior, National Biological Service, Washington, D.C.
- Clubb, S. L., R. M. Schubot, K. Joyner, J. G. Zinkl, S. Wolf, J. Esobar and M. B. Kabbur. 1991. Hematological and serum biochemical reference intervals in juvenile Cockatoos. *Journal of the Association of Avian Veterinarians* 5 (1): 16-26.
- Consolidated Veterinary Diagnostics Inc. 1995. Hematology - avian and small mammal. Page 3.5 in *Hematology laboratory protocols* 8/91.
- Dein, F. J. 1982. Avian hematology. Pages 5-29 in *Proceedings of the American association of avian veterinarians*.
- Duncan, R. J., K. W. Prasse and E. A. Mahaffey. 1994. Pages 37-129 in *Veterinary Laboratory Medicine Clinical Pathology* (3rd edition). Iowa State Press, Ames, Iowa.
- Franson, C. J., H. C. Murray and C. Bunck. 1982. Enzyme activities in plasma, liver, kidney of Black Ducks and Mallards. *Journal of Wildlife Disease* 18: 481-486.
- Gaunt, S. D., J. S. Prescott-Mathews, W. K. King and D. T. Scholl. 1996. Clinical hematology practices at veterinary teaching hospitals and private diagnostic laboratories. *Veterinary Clinical Pathology* 24 (2): 64-67.
- Ghebremeskel, K., T. D. Williams, D. A. Gardner and M. A. Crawfors. 1991. Plasma metabolites in Macaroni Penguins (*Eudyptes chrysolophus*) arriving on land for breeding and molting. *Comparative Biochemistry and Physiology* 99: 245-250.
- Halliwell, W. H. 1971. Serum chemistry profiles in health and disease of birds of prey. Pages 11-112 in *Recent advances in the study of raptor diseases* (J. E. Cooper and A. G. Greenwood, Eds.). Chiron Publications Limited, West Yorkshire, England.
- Harrison, G. J., A. H. Lewandowski and T. W. Campbell. 1986. Clinical chemistries. Pages 192-201 in *Clinical avian medicine and surgery* (G. Harrison and L. Harrison, Eds.). W. B. Saunders and Company, Philadelphia.
- Hawkey, C. M. and H. J. Samour. 1988. The value of clinical hematology in exotic birds. Pages 109-141 in *Exotic animals* (E. R. Jacobson and G. V. Kollias, Eds.). Churchill Livingstone, New York, New York.
- ISIS. 1983. Normal physiological data. International Species Inventory System (ISIS), Apple Valley, Minnesota.
- Ivins, G. K., G. D. Weddle, and W. H. Halliwell. 1978. Hematology and serum chemistries in birds of prey. Page 286 in *Zoo and wild animal medicine*, 1st edition (M. B. Fowler, Ed.). W. B. Saunders and Company, Philadelphia, Pennsylvania.
- King, A. S. and J. McLelland (Eds.). 1984. Pages 175-186 in *Birds their structure and function*, 2nd edition. Balliere Tindall, Philadelphia, Pennsylvania.
- King, K. A., S. Macko, P. L. Parker and E. Payne. 1979. Resuspension of oil; Probable cause of Brown Pelican fatality. *Bulletin of Environmental Contamination and Toxicology* 23: 800-805.
- Kocan, R. M. 1972. Some physiological blood values of wild diving ducks. *Journal of Wildlife Diseases* 8: 115-119.
- Leonard, J. L. 1969. Clinical laboratory examinations. Pages 189-215 in *Diseases in caged and aviary birds*, (M. L. Petrak, Ed.). Lea and Febiger, Philadelphia, Pennsylvania.
- Leighton, F. A. 1982. The pathophysiology of petroleum oil toxicity in birds (D. Rosie and S. N. Barnes Eds.). Tri-State Bird Rescue and Research Incorporated, Wilmington, Maryland.
- Lucas, A. M. and C. Jamroz. 1961. Atlas of avian hematology. U.S. Department of Agriculture, Animal Husbandry Research Division, U.S. Printing Office, Washington, D.C., monograph 25.
- Lumeij, J. T. 1987. Plasma urea, creatine and uric acid concentrations in response to dehydration in Racing Pigeons (*Columba livia domestica*). *Avian Pathology* 16: 377-382.
- Martin, H. F., B. J. Gudzinowicz and H. Fanger. 1975. Normal values in clinical chemistry: a guide to statistical analysis of laboratory data. Macel Dekker, New York, New York.
- Melrose, W. D. and S. C. Nicol. 1992. Haematology, red cell metabolism and blood chemistry of the Black-faced Cormorant *Leucocarbo fuscescens*. *Comparative Biochemistry and Physiology* 102A: 67-70.
- Newman, S. 1994. Oil spill rehabilitation: Beware of research. *Pacific Seabird Bulletin* 22(2):2.
- Newman, S. 1995. Utilization of blood parameters to improve marine bird rehabilitation. Pages 143-146 in *Effects of oil on wildlife*, proceedings from the fourth international conference, Seattle, Washington.
- Newman, S. H. 1996. Analyses of blood parameters from Common Murres (*Uria aalge*) collected from Yaquina Head, OR: A comparison to murres from southeast Farallon Island, CA and the Shumigan Islands, AK. Unpublished report, U.S. Fish and Wildlife Ser-

- vice, Oregon State Office, 2600 SE 98th Avenue, Portland, OR, 97266.
- Newman, S. H. and J. G. Zinkl. 1996. Establishment of hematological, serum biochemical and electrophoretogram reference intervals for species of marine birds likely to be impacted by oil spill incidents in the state of California; Final baseline marine bird project report (FG 3460-OS), California Department of Fish and Game, Office of Oil Spill Prevention and Response.
- Piatt, J. F. and C. J. Lensink. 1989. Exxon Valdez bird toll. *Nature* 342: 865-866.
- Piatt, J. F., H. R. Carter and D. N. Nettleship. 1990. Effects of oil pollution on marine bird populations. Pages 125-142 in *The effects of oil on wildlife*, Proceedings from the Oil Symposium, Herndon, Virginia.
- Puls, R. 1994. Mineral levels in animal health. (2nd edition). Sherpa International, Clearbrook, British Columbia, Canada.
- Robards, M. D., J. F. Piatt and K. D. Wohl. 1995. Increasing frequency of plastic particles ingested by seabirds in the subarctic north Pacific. *Marine Pollution Bulletin* 30: 151-157.
- Rocke, T. 1997. Type C botulism in fish-eating birds at the Salton Sea, California. Page 85 in *Proceedings from the 46th Wildlife Disease Association conference*, St. Petersburg, Florida.
- Rosa, C. D., R. Rosa, E. Rodriguez and M. Bacila. 1993. Blood constituents and electrophoretic patterns in Antarctic birds: Penguins and skuas. *Comparative Biochemistry and Physiology* 104A: 117-123.
- Roszkopf, W. J., R. W. Woerpel, G. Roszkopf and D. Van DeWater. 1982. Normal hematologic and blood chemistry values for pet avian species. Pages 143-145 in *Proceedings from 31st Western Poultry Disease conference*.
- Russel, M. 1996. Recovery of birds from the Santa Clara River oil spill. in *Proceedings of the National Wildlife Rehabilitation Association conference*, Houston, Texas (in press).
- Sharp, B. E. 1996. Post-release survival of oiled, cleaned seabirds in North America. *Ibis* 138: 222-228.
- Smith, E. and M. Bush. 1978. Haematologic parameters of various species of Strigiformes and Falconiformes. *Journal of Wildlife Diseases* 14: 447.
- Underhill, L. G., M. Thornton, R. J. M. Crawford, B. M. Dyer, L. Upfold, A. J. Williams, A. Gildenhuys and L. Baumann. 1994. Jackass Penguins, flipper bands and the *Apollo Sea* Incident. Pages 39-45 in *Proceedings from coastal oil spills: Effect on penguin communities and rehabilitation procedures*, Tyberg Nature Reserve, South Africa.
- White, J. 1994. Oiled Avian Triage Report. Pages 51-81 in *Report for California Department of Fish and Game, Office of Oil Spill Prevention and Response*.
- Williams, T. 1994. *Apollo Sea* afterworld, capture and treatment. Pages 48-49 in *Proceedings from coastal oil spills: Effect on penguin communities and rehabilitation procedures*, Tyberg Nature Reserve, South Africa.
- Wobeser, G. A., (Ed.). 1981. *Diseases of wild waterfowl*. Plenum Press, New York.
- Wolf, S. H., R. W. Schreiber, L. Kahana and J. J. Torres. 1985. Seasonal, sexual and age-related variation in the blood composition of the Brown Pelican (*Pelicanus occidentalis*). *Journal of Comparative Biochemistry and Physiology*, volume 82A: 837-846.
- Work, T. M. 1996. Weights, hematology, and serum chemistry of seven species of free ranging tropical pelagic seabirds. *Journal of Wildlife Diseases*, 32 (4): 643-657.