RELATIVE WILDLIFE HAZARD SCORES FOR U.S. NAVY, MARINE CORP, AND U.S AIR FORCE FIXED-WING AIRCRAFT
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I. Executive Summary

Knowledge on the relative hazards of wildlife (the likelihood of aircraft damage when a species is struck) is needed before estimating strike risk (combined frequency and severity component) between wildlife and aircraft at local airfields. We hypothesized that military relative hazards scores would correlate positively with aircraft type and avian body mass. Only strike records identified to species and occurred within an U.S. airfield environment ($n = 39{,}748$) with U.S. Navy or U.S. Air Force aircraft were used to calculate relative hazard scores. The most hazardous species to military fixed-wing aircraft was the snow goose (*Chen caerulescens*), followed by the common loon (*Gavia immer*), and Canada goose (*Branta canadensis*). Among both military branches and aircraft types, there was a positive association between body mass and relative hazard score (coefficient of determination, $r^2 = 0.77$). In general, relative hazard scores were higher for military than civil airframes, regardless of avian body mass. Another important consideration for wildlife management is that hazard scores vary depending on aircraft type.

II.   Background

Reviews of wildlife strike trends with civil aviation have been conducted regularly since the early 1990s (Cleary, Wright et al. 1999, Dolbeer, Wright et al. 2000, Dolbeer, Wright et al. 2016) however, very little is known about wildlife strike trends with military fixed-wing aircraft (Zakrajsek and Bissonette 2005). According to U.S. Navy (USN) wildlife strike database from 1990-2017 an average of $20 million in damage were attributed to wildlife strikes per annum (Navy wildlife strike database). For a similar time period (1994-2017), the U.S. Air Force (USAF) experienced an average of $38 million per annum in damage and human injuries caused by wildlife strikes (USAF wildlife strike database). To mitigate this risk of wildlife strikes, most U.S. military bases with a flying mission require a Bird/Wildlife/Animal Aircraft Strike Hazard program.

However, over 700 wildlife species have been struck by military aircraft, which can complicate species-specific management efforts at military airfields (Navy and USAF wildlife strike databas⬚ A necessary component for prioritizing resources and time for mitigating wildlife strikes is the ranking of wildlife by the hazard they pose to aviation, as a component of strike risk (DeVault, Blackwell et al. 2018). Severity of a strike with an animal (hazard) and a frequency measure (i.e. how often strikes occur per species) are the two components to estimate strike risk (DeVault, Blackwell et al. 2018). As hazard rankings have not been calculated for military aircraft, our objective was to calculate hazard scores.

Military and civil operations differ in their mission types, including air speeds and maneuverability, which could affect wildlife hazard scores. During certain training procedures, military aircraft travel at high speeds and close to the ground, which likely increases the relative hazard compared to civil aircraft because of more time spent in bird rich altitudes (Dolbeer

2006). Furthermore, because damage to aircraft is a function of kinetic energy which is the product of the mass of the bird in relation to the velocity of the aircraft (Einstein 1922), birds with smaller body mass might pose a more substantial hazard to military than civil aircraft.

We predicted that airframe type and avian body mass would contribute markedly to predicting hazard levels for military aircraft. Furthermore, significant relationships between body mass and relative hazard scores could be used to calculate hazard scores for species that are not currently in our dataset (e.g. solve the equation for relative hazard score based on avian body mass).

III. Methods

We used wildlife strike records from two databases maintained by the USN and the USAF. The USN wildlife strike database spanned 27 years (1990 – 2017) and contained 21,661 wildlife strike records. This dataset was corroborated with the records from the Smithsonian Institution's Feather Identification Lab, which identifies wildlife remains based on DNA and/or feathers (Marra, Dove et al. 2009), to increase the sample size of records identified to species level. The USAF dataset spanned 1994-2017 and contained 104,129 wildlife strike records. We filtered these databases to only include strikes that occurred within the U.S. (including Alaska and Hawaii) where the species involved in the strike was identified. We did not filter strikes by altitude (i.e. < 152 m), which was done in similar studies to focus on the airport environment (DeVault, Belant et al. 2011). Military aircraft do not adhere to the 3º glide slope of ascent and decent of civil aircraft, from which the threshold of 152 m is based (Flight Safety Foundation 2000) and routinely conduct low level flights. If multiple animals were involved in one strike event, they are entered as separate strikes, but with the same report number. To prevent duplication, only one strike per event was used (i.e. duplicate report numbers were removed). Duplicate report numbers were removed based on body size; the larger of the two species was retained. Furthermore, only species with more than 20 strikes were used in our analyses (DeVault, Blackwell et al. 2016, DeVault, Blackwell et al. 2018). To reduce complexity and facilitate management decisions, those species with less than 50 strikes were combined into species groups (Supplemental Table 1) based on phylogeny (Poole 2005).

The military databases were filtered by their damage class (Supplemental Table 2). Strikes for which class severity was unknown were considered to be non-damaging. In the USN dataset, there were no non-damaging strikes (strike severity was unknown), which is needed for

the hazard score analysis. After discussions with USN personnel, we separated Class H strikes in the USN dataset into damaging (≥ $55 of damage costs) or non-damaging (< $55 of damage costs) strikes. The $55 threshold is the average cost of collecting wildlife remains from an aircraft after a strike occurs, and does not indicate damage to the aircraft. We considered strikes with class severity of A/B/C as consisting of substantial damage and D/E/H as causing damage. We then calculated separately the percentage of total strikes for each species group that resulted in damage and substantial damage (DeVault, Belant et al. 2011, DeVault, Blackwell et al. 2016). Previous hazard rankings also included a metric called 'effect on flight', however this metric was only recorded for the USAF and not the USN, therefore, effect on flight was omitted.

We ranked species groups in terms of the two hazard metrics (percentage strikes with damage and percentage of strikes with substantial damage), as per Dolbeer et al. (2000). A composite rank was calculated by summing the hazard metric ranks, and then the species groups were ordered from most to least hazardous, and included tied ranks. The relative hazard score was calculated by summing the scores of the two hazard metrics for each species group scaled to 100 (Dolbeer, Wright et al. 2000). Relative hazard scores were calculated for the combined USN and USAF datasets, and then separately to investigate differences of suspected strike reporting rates. Airframe types were grouped by those similar in mission type (Supplemental Table 3). Airframe groups were suggested by military pilots and aviation experts and included three groups: fighter, cargo, and stealth airframes. Some airframes could be classified in multiple categories (i.e. F-35 is considered a stealth fighter). For our purposes we grouped airframe by mission type (quick maneuverability, moving payloads, or surveillance missions), which may differ from traditional airframe groups. We highlight these unique airframe types in Supplemental Table 3. Relative hazard scores were then calculated for each of the airframe types

separately. We investigated differences in relative hazard scores of species groups between

military branches and airframes using the chi-square test for goodness of fit (Conover and

Conover 1980).

We investigate the relationship between relative hazard score and avian body mass using

averaged body mass data, in which masses were averaged when they differed among avian sexes

(Dunning 1992). For species 'groups', we averaged the body masses based on the respective

number of strikes for each species in the group. The bird body masses were log-transformed to

normalize the data. We regressed relative hazard scores against log body masses for the

combined datasets, USN only, USAF only, and the three airframe groups with species-groups as

the sample units in a quadratic function. Model fit was assessed by the coefficient of

determination (r^2 value) and p value ($\alpha = 0.05$) (Nagelkerke 1991). All database filtering and

data analyses were conducted in R ver. 3.4.3. (R Core Team 2017). Code for the statistical

program R is supplied in Appendix A.

IV. Results

After removing strikes that occurred in other countries and were not identified to species, the USAF dataset was reduced to 36,767 wildlife strikes. The USN dataset contained 4,433 records that met the aforementioned criteria. Combining the USN and USAF resulted in 41,200 records. Only including strikes with species that were struck more than 20 times reduced the sample to 39,748 strikes for the combined USN and USAF datasets.

A total of 197 wildlife species were involved in 20 or more strikes with USN and USAF aircraft, and 3 species were struck more than 2,000 times: horned lark (*Eremophila alpestris*), mourning dove (*Zenaida macroura*), and barn swallow (*Hirundo rustica*). The wildlife species were grouped into 111 groups, 108 were avian. Out of these species groups, the percentage of strikes with some level of damage ranged from 1% (burrowing owl [*Athene cunicularia*]) to 76 % (snow goose [*Chen caerulescens*]). There were 29 species groups that were involved in strikes with no substantial damage (Table 1). The species involved in the highest percentage of strikes with substantial damage was the snow goose (43%). The top three species by their hazard composite rank were snow goose, common loon (*Gavia immer*), and Canada goose (*Branta canadensis*) (Table 1). Relative hazard scores were calculated separately for the USN and USAF datasets (Table 2 and Table 3). Hazard scores for species groups ($n = 44$ similar between USN and USAF) ranked in both datasets differed between the military branches ($\chi^2_{42} = 299.54$ $P < 0.001$, Table 4). In the USAF dataset, 32 out of 44 species groups had higher relative hazard scores than the USN dataset.

Table 1. Wildlife hazard rankings for 111 species groups from most to least hazardous for military aircraft within the U.S. (including Alaska and Hawaii).

Species	Total strikes reported	Non-damaging strikes	% with damage	Damage rank	% with substantial damage	Substantial damage rank	Relative hazard score	Composite rank
Snow goose (*Chen caerulescens*)	49	12	76	1	43	1	100	1
Common loon (*Gavia immer*)	21	7	67	2	33	2	84	2
Canada goose (*Branta canadensis*)	62	27	56	4	29	3	72	3
Black vulture (*Coragyps atratus*)	456	190	58	3	25	5	71	4
White-tailed deer (*Odocoileus virginianus*)	22	10	55	5	27	4	69	5
Turkey vulture (*Cathartes aura*)	615	313	49	6	22	6	60	6
Northern pintail (*Anas acuta*)	93	52	44	8	16	8	51	7
Mallard (*Anas platyrhynchos*)	215	115	47	7	13	13	50	8
Double-crested cormorant (*Phalacrocorax auritus*)	46	26	43	9	13	12	48	9
Swainson's hawk (*Buteo swainsoni*)	130	77	41	11	14	10	46	9
Red-tailed hawk (*Buteo jamaicensis*)	617	388	37	13	14	9	43	11
Herring gull (*Larus argentatus*)	126	85	33	16	18	7	43	12
Bald eagle (*Haliaeetus leucocephalus*)	34	20	41	10	12	14	45	13
Pied-billed grebe (*Podilymbus podiceps*)	30	20	33	15	13	11	39	14
Osprey (*Pandion haliaetus*)	85	53	38	12	9	17	40	15
Other ducks	364	231	37	14	10	16	39	16
Great blue heron (*Ardea herodias*)	63	43	32	17	11	15	36	17
Other egrets	26	19	27	20	8	20	29	18
Other hawks	250	181	28	19	7	23	29	19
American coot (*Fulica americana*)	193	139	28	18	5	26	28	20
Cattle egret (*Bubulcus ibis*)	71	57	20	25	7	21	23	21
Ring-billed gull (*Larus delawarensis*)	205	167	19	27	8	19	22	21
Sprague's pipit (*Anthus spragueii*)	24	20	17	31	8	18	21	23
White-winged dove (*Zenaida asiatica*)	160	128	20	24	5	27	21	24

Common grackle (*Quiscalus quiscula*)	65	53	18	28	6	25	21	25
Great horned owl (*Bubo virginianus*)	99	79	20	23	4	32	20	26
Mississippi kite (*Ictinia mississippiensis*)	73	55	25	21	3	35	23	27
Other falcons	73	62	15	34	7	22	19	27
Other gulls	254	210	17	29	5	28	19	29
American crow (*Corvus brachyrhynchos*)	47	41	13	39	6	24	16	30
Rock dove (*Columba livia*)	326	273	16	32	4	31	17	30
Vaux's swift (*Chaetura vauxi*)	23	20	13	37	4	30	15	32
White-throated swift (*Aeronautes saxatalis*)	177	151	15	35	4	33	16	33
Yellow-billed cuckoo (*Coccyzus americanus*)	210	176	16	33	2	40	15	34
European starling (*Sturnus vulgaris*)	315	275	13	40	3	34	14	35
Barn owl (*Tyto alba*)	111	98	12	43	3	36	12	36
Other blackbirds	44	40	9	58	5	29	12	37
Scarlet tanager (*Piranga olivacea*)	82	70	15	36	1	51	13	37
Black-bellied plover (*Pluvialis squatarola*)	78	68	13	38	1	50	12	39
Other doves	62	55	11	45	2	44	11	40
Purple martin (*Progne subis*)	298	263	12	42	1	49	11	41
American robin (*Turdus migratorius*)	962	861	10	51	2	42	10	42
Yellow-bellied sapsucker (*Sphyrapicus varius*)	87	79	9	55	2	38	10	42
Other plovers	130	116	11	49	2	45	10	44
Baltimore oriole (*Icterus galbula*)	82	75	9	61	2	37	9	45
Other shorebirds	205	186	9	54	1	47	9	46
Mourning dove (*Zenaida macroura*)	2957	2686	9	57	1	46	9	47
Brown-headed cowbird (*Molothrus ater*)	102	91	11	48	1	56	10	48
Northern flicker (*Colaptes auratus*)	48	38	21	22	0	83	18	49
Cave swallow (*Petrochelidon fulva*)	126	112	11	46	1	61	10	50
Other thrushes	533	472	11	44	1	63	10	50
Ovenbird (*Seiurus aurocapillus*)	182	167	8	65	2	43	8	52
Brown thrasher (*Toxostoma rufum*)	51	41	20	26	0	83	17	53
Cardinals, grosbeaks, and allies	114	102	11	50	1	59	10	53

Great crested flycatcher (*Myiarchus crinitus*)	71	65	8	63	1	48	8	55
Red-winged blackbird (*Agelaius phoeniceus*)	200	186	7	72	2	39	8	55
Wood thrush (*Hylocichla mustelina*)	105	87	17	30	0	83	14	57
Meadowlarks	1908	1780	7	74	2	41	7	58
Gray catbird (*Dumetella carolinensis*)	370	330	11	47	1	69	10	59
Ruby-crowned kinglet (*Regulus calendula*)	89	82	8	66	1	53	8	60
American kestrel (*Falco sparverius*)	1231	1142	7	70	1	52	7	61
Violet-green swallow (*Tachycineta thalassina*)	33	29	12	41	0	83	10	62
Scissor-tailed flycatcher (*Tyrannus forficatus*)	196	178	9	56	1	72	8	63
Blue-gray gnatcatcher (*Polioptila caerulea*)	151	140	7	69	1	66	7	64
Sora (*Porzana carolina*)	125	112	10	52	0	83	9	64
Semipalmated sandpiper (*Calidris pusilla*)	21	19	10	53	0	83	8	66
Orchard oriole (*Icterus spurius*)	22	20	9	58	0	83	8	67
Bats	1882	1747	7	71	1	71	7	68
House wren (*Troglodytes aedon*)	94	89	5	89	1	54	5	69
Northern mockingbird (*Mimus polyglottos*)	68	62	9	60	0	83	7	69
Killdeer (*Charadrius vociferous*)	1621	1527	6	84	1	60	6	71
Other wood warblers	1288	1203	7	76	1	68	6	71
Coyote (*Canis latrans*)	47	43	9	62	0	83	7	73
Red-eyed vireo (*Vireo olivaceus*)	376	351	7	75	1	70	6	73
Other flycatchers	178	163	8	64	0	83	7	75
Barn swallow (*Hirundo rustica*)	2188	2056	6	82	1	67	6	76
Indigo bunting (*Passerina cyanea*)	131	124	5	88	1	62	5	77
Upland sandpiper (*Bartramia longicauda*)	140	129	8	67	0	83	7	77
Dunlin (*Calidris alpine*)	52	48	8	68	0	83	6	79
Ruby-throated hummingbird (*Archilochus colubris*)	148	138	7	73	0	83	6	80
Horned lark (*Eremophila alpestris*)	3274	3120	5	99	1	58	5	81
Chimney swift (*Chaetura pelagica*)	1253	1173	6	79	0	79	6	82
Hermit thrush (*Catharus guttatus*)	263	247	6	81	0	77	5	82
American goldfinch (*Spinus tristis*)	61	57	7	77	0	83	6	84

Species								
Lapland longspur (*Calcarius lapponicus*)	141	134	5	95	1	65	5	84
Short-eared owl (*Asio flammeus*)	61	57	7	77	0	83	6	84
Cedar waxwing (*Bombycilla cedrorum*)	295	278	6	85	0	78	5	87
Cliff swallow (*Petrochelidon pyrrhonota*)	1296	1218	6	83	0	80	5	87
Other wrens	49	46	6	80	0	83	5	87
Western kingbird (*Tyrannus verticalis*)	195	187	4	108	1	55	4	87
American pipit (*Anthus rubescens*)	216	207	4	107	1	57	4	91
Common yellowthroat (*Geothlypis trichas*)	218	207	5	92	0	74	5	92
Common nighthawk (*Chordeiles minor*)	700	669	4	104	1	64	4	93
Common snipe (*Gallinago gallinago*)	70	66	6	86	0	83	5	94
Other vireos	182	172	5	87	0	83	5	95
Bank swallow (*Riparia riparia*)	151	143	5	90	0	83	4	96
Golden-crowned kinglet (*Regulus satrapa*)	38	36	5	91	0	83	4	97
Other sparrows	2181	2080	5	100	0	75	4	98
Least sandpiper (*Calidris minutilla*)	60	57	5	93	0	83	4	99
Lesser nighthawk (*Chordeiles acutipennis*)	80	76	5	93	0	83	4	99
Yellow-rumped Warbler (*Setophaga coronate*)	524	498	5	96	0	82	4	101
Other longspurs	82	78	5	97	0	83	4	102
House finch (*Haemorhous mexicanus*)	63	60	5	98	0	83	4	103
Dark-eyed junco (*Junco hyemalis*)	261	250	4	106	0	76	4	104
Savannah sparrow (*Passerculus sandwichensis*)	816	784	4	109	0	73	4	104
Tree swallow (*Tachycineta bicolor*)	328	313	5	102	0	81	4	106
Snow bunting (*Plectrophenax nivalis*)	65	62	5	101	0	83	4	107
Bobolink (*Dolichonyx oryzivorus*)	66	63	5	103	0	83	4	108
Wilson's snipe (*Gallinago delicate*)	70	67	4	105	0	83	4	109
Other terns	44	43	2	110	0	83	2	110
Burrowing owl (*Athene cunicularia*)	81	80	1	111	0	83	1	111

The composite rank represents the sum of the percentage of strikes with damage and the percentage of strikes with substantial damage for that species group. See Supplemental Table 1 for a list of species in each species group (i.e. Other ducks). Strike data are from separate databases maintained by the Navy (1990-2017) and USAF (1994-2017).

Table 2. Wildlife hazard rankings for 46 species groups from most to least hazardous for USN military aircraft within the U.S. (including Alaska and Hawaii).

Species	Total strikes reported	Non-damaging strikes	% with damage	Damage rank	% with substantial damage	Substantial damage rank	Relative hazard score	Composite rank
Black vulture (*Coragyps atratus*)	45	26	42	1	7	1	100	1
Ring-billed gull (*Larus delawarensis*)	22	17	23	5	5	3	56	2
Purple martin (*Progne subis*)	48	37	23	4	2	6	51	3
Red-tailed hawk (*Buteo jamaicensis*)	69	56	19	7	4	4	47	4
Turkey vulture (*Cathartes aura*)	127	102	20	6	4	5	48	4
Cave swallow (*Petrochelidon fulva*)	36	25	31	2	0	10	63	6
Other hawks	39	29	26	3	0	10	52	7
Blue-gray gnatcatcher (*Polioptila caerulea*)	48	39	19	8	0	10	38	8
Osprey (*Pandion haliaetus*)	28	23	18	9	0	10	37	9
Other flycatchers	29	25	14	10	0	10	28	10
Other thrushes	53	46	13	11	0	10	27	11
Great crested flycatcher (*Myiarchus crinitus*)	23	20	13	12	0	10	27	12
Other vireos	23	20	13	12	0	10	27	12
Mourning dove (*Zenaida macroura*)	201	177	12	14	0	9	25	14
Horned lark (*Eremophila alpestris*)	187	169	10	18	1	7	22	15
Savannah sparrow (*Passerculus sandwichensis*)	89	79	11	15	0	10	23	15
Meadowlarks	144	129	10	16	0	10	21	17
Other plovers	20	18	10	17	0	10	20	18
Gray catbird (*Dumetella carolinensis*)	52	47	10	19	0	10	20	19
Cliff swallow (*Petrochelidon pyrrhonota*)	148	134	9	20	0	10	19	20
Other doves	22	20	9	21	0	10	19	21
Yellow-billed cuckoo (*Coccyzus americanus*)	33	30	9	21	0	10	19	21
Other sparrows	104	95	9	23	0	10	18	23

Species							
Other gulls	83	76	8	24	0	10	17	24
Chimney swift (*Chaetura pelagica*)	134	123	8	25	0	10	17	25
Other shorebirds	26	24	8	26	0	10	16	26
Bats	275	258	6	29	1	8	14	27
Other terns	21	20	5	35	5	2	19	27
Other wood warblers	220	206	6	27	0	10	13	27
Barn swallow (*Hirundo rustica*)	257	241	6	28	0	10	13	30
Other ducks	35	33	6	30	0	10	12	31
Ruby-throated hummingbird (*Archilochus colubris*)	53	50	6	31	0	10	12	32
Cedar waxwing (*Bombycilla cedrorum*)	37	35	5	32	0	10	11	33
Red-eyed vireo (*Vireo olivaceus*)	61	58	5	33	0	10	10	34
Tree swallow (*Tachycineta bicolor*)	61	58	5	33	0	10	10	34
Coyote (*Canis latrans*)	22	21	5	36	0	10	9	36
Killdeer (*Charadrius vociferous*)	137	132	4	37	0	10	7	37
American robin (*Turdus migratorius*)	58	56	3	38	0	10	7	38
Yellow-rumped Warbler (*Setophaga coronate*)	104	101	3	39	0	10	6	39
Common nighthawk (*Chordeiles minor*)	38	37	3	40	0	10	5	40
American kestrel (*Falco sparverius*)	84	83	1	41	0	10	2	41
Barn owl (*Tyto alba*)	27	27	0	42	0	10	0	42
Common yellowthroat (*Geothlypis trichas*)	32	32	0	42	0	10	0	42
European starling (*Sturnus vulgaris*)	22	22	0	42	0	10	0	42
Indigo bunting (*Passerina cyanea*)	39	39	0	42	0	10	0	42
Ovenbird (*Seiurus aurocapillus*)	24	24	0	42	0	10	0	42

The composite rank represents the sum of the percentage of strikes with damage and the percentage of strikes with substantial damage for that species group. See Supplemental Table 1 for a list of species in each species group (i.e. Other ducks). Strike data are from a database maintained by the Navy (1990-2017).

Table 3 Wildlife hazard rankings for 109 species groups from most to least hazardous for USAF military aircraft within the U.S. (including Alaska and Hawaii).

Species	Total strikes reported	Non-damaging strikes	% with damage	Damage rank	% with substantial damage	Substantial damage rank	Relative hazard score	Composite rank
Snow goose (*Chen caerulescens*)	49	12	76	1	43	1	100	1
Common loon (*Gavia immer*)	21	6	71	2	33	2	89	2
Canada goose (*Branta canadensis*)	59	24	59	5	31	3	76	3
Black vulture (*Coragyps atratus*)	420	168	60	4	27	5	73	4
Bald eagle (*Haliaeetus leucocephalus*)	21	8	62	3	19	8	68	5
White-tailed deer (*Odocoileus virginianus*)	22	10	55	7	27	4	69	5
Turkey vulture (*Cathartes aura*)	513	229	55	6	26	6	68	7
Double-crested cormorant (*Phalacrocorax auritus*)	40	19	53	8	15	10	57	8
Northern pintail (*Anas acuta*)	85	46	46	10	16	9	53	9
Herring gull (*Larus argentatus*)	109	68	38	15	21	7	50	10
Mallard (*Anas platyrhynchos*)	202	104	49	9	14	13	53	10
Swainson's hawk (*Buteo swainsoni*)	121	68	44	11	15	11	50	10
Osprey (*Pandion haliaetus*)	64	37	42	12	13	14	46	13
Red-tailed hawk (*Buteo jamaicensis*)	566	346	39	14	15	12	45	13
Other ducks	342	208	39	13	11	17	42	15
Pied-billed grebe (*Podilymbus podiceps*)	32	22	31	17	13	14	37	16
Great blue heron (*Ardea herodias*)	58	38	34	16	12	16	39	17
Other egrets	22	16	27	20	9	19	31	18
Other hawks	222	161	27	19	8	23	30	19
Cattle egret (*Bubulcus ibis*)	62	48	23	22	8	21	26	20
American coot (*Fulica americana*)	190	133	30	18	5	27	30	21
Other falcons	58	47	19	28	9	20	23	22
Ring-billed gull (*Larus delawarensis*)	189	154	19	29	8	22	22	23

Species								
Common grackle (*Quiscalus quiscula*)	62	50	19	27	6	25	22	24
Other gulls	198	159	20	26	6	26	22	24
Great horned owl (*Bubo virginianus*)	87	68	22	23	5	31	22	26
Mississippi kite (*Ictinia mississippiensis*)	66	49	26	21	3	36	24	27
White-winged dove (*Zenaida asiatica*)	154	126	18	30	5	28	20	28
American crow (*Corvus brachyrhynchos*)	40	34	15	35	8	24	19	29
Rock dove (*Columba livia*)	334	281	16	33	4	32	17	30
Vaux's swift (*Chaetura vauxi*)	21	18	14	38	5	29	16	31
Sprague's pipit (*Anthus spragueii*)	20	18	10	50	10	18	17	32
Barn owl (*Tyto alba*)	84	71	15	34	4	35	16	33
Yellow-billed cuckoo (*Coccyzus americanus*)	198	166	16	32	3	38	16	34
White-throated swift (*Aeronautes saxatalis*)	177	153	14	39	4	33	15	35
European starling (*Sturnus vulgaris*)	298	258	13	40	4	34	14	36
Other doves	40	35	13	42	3	39	13	37
Black-bellied plover (*Pluvialis squatarola*)	68	58	15	36	1	49	14	38
Other blackbirds	43	39	9	56	5	30	12	39
Baltimore oriole (*Icterus galbula*)	70	63	10	50	3	37	11	40
Scarlet tanager (*Piranga olivacea*)	75	64	15	37	1	50	14	40
Other plovers	110	98	11	44	2	45	11	42
American robin (*Turdus migratorius*)	921	821	11	45	2	46	11	43
Yellow-bellied sapsucker (*Sphyrapicus varius*)	84	76	10	54	2	40	10	44
Ovenbird (*Seiurus aurocapillus*)	175	159	9	58	2	41	10	45
Other shorebirds	181	164	9	55	2	47	9	46
Brown-headed cowbird (*Molothrus ater*)	103	92	11	46	1	58	10	47
Brown thrasher (*Toxostoma rufum*)	49	39	20	24	0	82	17	48
Northern flicker (*Colaptes auratus*)	49	39	20	24	0	82	17	48
Other thrushes	502	446	11	43	1	63	10	48
Red-winged blackbird (*Agelaius phoeniceus*)	187	173	7	64	2	42	8	48
Mourning dove (*Zenaida macroura*)	2779	2527	9	59	2	48	9	52
Purple martin (*Progne subis*)	260	236	9	57	1	52	9	53

Cardinals, grosbeaks, and allies	102	92	10	53	1	57	9	54
American kestrel (*Falco sparverius*)	1153	1064	8	62	1	51	8	55
Wood thrush (*Hylocichla mustelina*)	100	82	18	31	0	82	15	55
Meadowlarks	1776	1663	6	71	2	43	7	57
Gray catbird (*Dumetella carolinensis*)	352	315	11	47	1	70	9	58
Ruby-crowned kinglet (*Regulus calendula*)	92	85	8	63	1	54	7	58
Violet-green swallow (*Tachycineta thalassina*)	30	26	13	41	0	82	11	60
Great crested flycatcher (*Myiarchus crinitus*)	54	51	6	81	2	44	6	61
Indigo bunting (*Passerina cyanea*)	103	96	7	67	1	58	7	61
Coyote (*Canis latrans*)	29	26	10	48	0	82	9	63
Sora (*Porzana carolina*)	116	104	10	48	0	82	9	63
Bats	1726	1599	7	65	1	66	7	65
Northern mockingbird (*Mimus polyglottos*)	70	63	10	50	0	82	8	66
Scissor-tailed flycatcher (*Tyrannus forficatus*)	189	172	9	60	1	72	8	66
Killdeer (*Charadrius vociferous*)	1498	1408	6	74	1	60	6	68
Red-eyed vireo (*Vireo olivaceus*)	348	325	7	70	1	69	6	69
Other wood warblers	1184	1111	6	72	1	68	6	70
Barn swallow (*Hirundo rustica*)	1954	1838	6	75	1	67	6	71
Lapland longspur (*Calcarius lapponicus*)	141	133	6	77	1	65	5	71
Short-eared owl (*Asio flammeus*)	57	52	9	61	0	82	7	73
American pipit (*Anthus rubescens*)	202	192	5	88	1	56	5	74
Hermit thrush (*Catharus guttatus*)	264	248	6	73	0	75	5	75
Other flycatchers	155	144	7	66	0	82	6	75
Ruby-throated hummingbird (*Archilochus colubris*)	103	96	7	67	0	82	6	77
Other wrens	45	42	7	69	0	82	6	78
Common nighthawk (*Chordeiles minor*)	676	644	5	91	1	64	5	79
Cave swallow (*Petrochelidon fulva*)	90	87	3	103	1	53	4	80
Chimney swift (*Chaetura pelagica*)	1185	1115	6	76	0	80	5	80
Western kingbird (*Tyrannus verticalis*)	192	185	4	101	1	55	4	80
Horned lark (*Eremophila alpestris*)	3161	3023	4	96	1	62	4	83

Cliff swallow (*Petrochelidon pyrrhonota*)	1172	1106	6	80	0	79	5	84
Common yellowthroat (*Geothlypis trichas*)	209	198	5	85	0	74	5	84
Cedar waxwing (*Bombycilla cedrorum*)	273	258	5	83	0	77	5	86
Upland sandpiper (*Bartramia longicauda*)	124	117	6	78	0	82	5	86
Common snipe (*Gallinago gallinago*)	71	67	6	79	0	82	5	88
American goldfinch (*Spinus tristis*)	54	51	6	81	0	82	5	89
Golden-crowned kinglet (*Regulus satrapa*)	37	35	5	84	0	82	5	90
Yellow-rumped Warbler (*Setophaga coronate*)	475	450	5	85	0	81	5	90
Other sparrows	2187	2087	5	94	1	73	4	92
Blue-gray gnatcatcher (*Polioptila caerulea*)	108	106	2	108	1	61	2	93
Lesser nighthawk (*Chordeiles acutipennis*)	79	75	5	87	0	82	4	93
Bank swallow (*Riparia riparia*)	144	137	5	89	0	82	4	95
Tree swallow (*Tachycineta bicolor*)	270	258	4	95	0	76	4	95
Bobolink (*Dolichonyx oryzivorus*)	63	60	5	90	0	82	4	97
Snow bunting (*Plectrophenax nivalis*)	64	61	5	92	0	82	4	98
Other longspurs	86	82	5	93	0	82	4	99
Savannah sparrow (*Passerculus sandwichensis*)	745	722	3	104	1	71	3	99
Dark-eyed junco (*Junco hyemalis*)	275	264	4	98	0	78	4	101
House wren (*Troglodytes aedon*)	97	93	4	97	0	82	3	102

The composite rank represents the sum of the percentage of strikes with damage and the percentage of strikes with substantial damage for that species group. See Supplemental Table 1 for a list of species in each species group (i.e. Other ducks). Strike data are from a database maintained by the USAF (1994-2017).

Table 4. Comparison of relative hazard scores for 44 species groups between the USN and USAF within the U.S. (including Alaska and Hawaii).

Species	Relative hazard score	
	Navy	USAF
American kestrel (*Falco sparverius*)	2	8
American robin (*Turdus migratorius*)	7	11
Barn owl (*Tyto alba*)	0	16
Barn swallow (*Hirundo rustica*)	13	6
Black vulture (*Coragyps atratus*)	100	73
Blue-gray gnatcatcher (*Polioptila caerulea*)	38	2
Cave swallow (*Petrochelidon fulva*)	63	4
Cedar waxwing (*Bombycilla cedrorum*)	11	5
Chimney swift (*Chaetura pelagica*)	17	5
Cliff swallow (*Petrochelidon pyrrhonota*)	19	5
Common nighthawk (*Chordeiles minor*)	5	5
Common yellowthroat (*Geothlypis trichas*)	0	5
European starling (*Sturnus vulgaris*)	0	14
Gray catbird (*Dumetella carolinensis*)	20	9
Great crested flycatcher (*Myiarchus crinitus*)	27	6
Horned lark (*Eremophila alpestris*)	22	4
Indigo bunting (*Passerina cyanea*)	0	7
Killdeer (*Charadrius vociferous*)	7	6
Meadowlarks	21	7
Mourning dove (*Zenaida macroura*)	25	9
Osprey (*Pandion haliaetus*)	37	46
Other doves	19	13
Other Ducks	12	42
Other flycatchers	28	6
Other gulls	17	22
Other hawks	52	30
Other plovers	20	11
Other shorebirds	16	9
Other sparrows	18	4
Other terns	19	3
Other thrushes	27	10
Other vireos	27	3
Other wood warblers	13	6
Ovenbird (*Seiurus aurocapillus*)	0	10
Purple martin (*Progne subis*)	51	9

Red-eyed vireo (*Vireo olivaceus*)	10	6
Red-tailed hawk (*Buteo jamaicensis*)	47	45
Ring-billed gull (*Larus delawarensis*)	56	22
Ruby-throated hummingbird (*Archilochus colubris*)	12	6
Savannah sparrow (*Passerculus sandwichensis*)	23	3
Tree swallow (*Tachycineta bicolor*)	10	4
Turkey vulture (*Cathartes aura*)	48	68
Yellow-billed cuckoo (*Coccyzus americanus*)	19	16
Yellow-rumped Warbler (*Setophaga coronate*)	6	5

There were 10,781 strike records for military fighter airframes (74 species struck over 20 times, Table 5), 22,738 records for cargo airframes (102 species struck over 20 times, Table 6), and 1,095 strike records for stealth airframes (15 species struck over 20 times, Table 7). There were 74 species groups that were similar for fighter and cargo airframes; however, only 15 were similar across all three aircraft types. Furthermore, there were only 11 species that were similar between the military airframe types and the civil relative hazard scores. Relative hazard scores for species groups across airframe types and all civil airframes differed significantly ($\chi^2_{30} = 66.25$, $P < 0.001$, Figure 1). Out of the groups compared, nine (82%) had higher relative hazard scores for the stealth than all civil airframes.
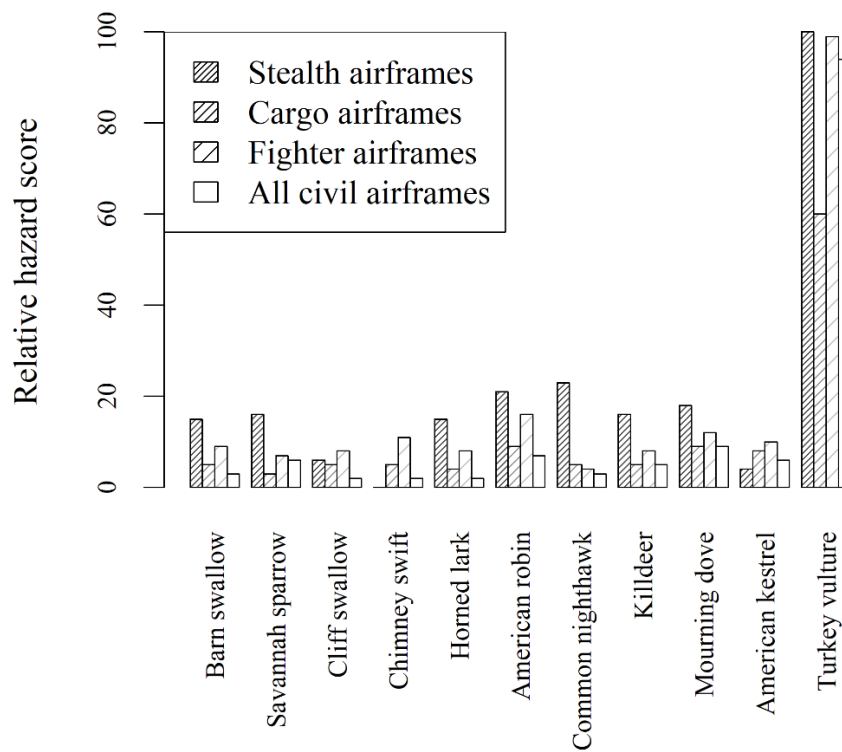

Figure 1. Comparison of relative hazard scores for 11 species groups for three military airframe types and all civil airframes. Relative hazard scores are calculated from wildlife strikes within the U.S. See Supplemental Table 3 for airframe group compositions. Civil relative hazard scores come from (DeVault, Blackwell et al. 2018). Species are ordered from left to right by averaged body mass.

1 Table 5. Wildlife hazard rankings for 74 species groups from most to least hazardous for fighter aircraft within the U.S. (including
2 Alaska and Hawaii).
3

Species	Total strikes reported	Non damaging strikes	% with damage	Damage rank	% with substantial damage	Substantial damage rank	Relative hazard score	Composite rank
Black vulture (*Coragyps atratus*)	114	56	51	1	19	3	100	1
Northern pintail (*Anas acuta*)	24	14	42	4	25	1	95	2
Turkey vulture (*Cathartes aura*)	172	88	49	3	21	2	99	2
Mallard (*Anas platyrhynchos*)	62	31	50	2	18	4	97	4
Red-tailed hawk (*Buteo jamaicensis*)	157	98	38	6	16	5	76	5
Swainson's hawk (*Buteo swainsoni*)	34	21	38	5	12	8	71	6
Herring gull (*Larus argentatus*)	39	27	31	9	15	6	66	7
Osprey (*Pandion haliaetus*)	24	16	33	8	13	7	65	7
Other ducks	81	52	36	7	11	9	67	9
Cattle egret (*Bubulcus ibis*)	21	16	24	13	10	10	47	10
Mississippi kite (*Ictinia mississippiensis*)	25	20	20	14	8	11	40	11
Other shorebirds	48	40	17	16	6	13	33	12
Other gulls	91	77	15	18	7	12	31	13
Ring-billed gull (*Larus delawarensis*)	58	49	16	17	5	14	29	14
Other hawks	74	54	27	10	4	22	44	15
American coot (*Fulica americana*)	48	36	25	12	4	21	42	16
House wren (*Troglodytes aedon*)	20	17	15	19	5	15	28	17
Yellow-billed cuckoo (*Coccyzus americanus*)	60	49	18	15	3	25	31	18
Black-bellied plover (*Pluvialis squatarola*)	27	23	15	20	4	23	26	19
White-throated swift (*Aeronautes saxatalis*)	45	39	13	25	4	18	25	19
White-winged dove (*Zenaida asiatica*)	43	38	12	29	5	16	23	21
Common grackle (*Quiscalus quiscula*)	23	20	13	27	4	19	25	22
Other plovers	29	25	14	22	3	24	25	22
Rock dove (*Columba livia*)	103	88	15	21	3	26	25	24

23

Other falcons	22	20	9	36	5	17	19	25
Great blue heron (*Ardea herodias*)	23	17	26	11	0	45	37	26
Ovenbird (*Seiurus aurocapillus*)	46	42	9	38	4	19	19	27
Barn owl (*Tyto alba*)	36	32	11	31	3	27	20	28
American robin (*Turdus migratorius*)	265	239	10	32	2	31	16	29
Other thrushes	142	123	13	24	1	39	20	29
European starling (*Sturnus vulgaris*)	85	77	9	35	1	33	15	31
Other doves	22	19	14	23	0	45	19	31
Great horned owl (*Bubo virginianus*)	38	33	13	26	0	45	19	33
Blue-gray gnatcatcher (*Polioptila caerulea*)	32	28	13	28	0	45	18	34
Cave swallow (*Petrochelidon fulva*)	35	31	11	30	0	45	16	35
Lapland longspur (*Calcarius lapponicus*)	42	39	7	48	2	28	14	36
Brown-headed cowbird (*Molothrus ater*)	21	19	10	33	0	45	14	37
Mourning dove (*Zenaida macroura*)	855	790	8	44	1	34	12	37
Scarlet tanager (*Piranga olivacea*)	21	19	10	33	0	45	14	37
Meadowlarks	525	489	7	50	2	29	12	40
Sora (*Porzana carolina*)	22	20	9	36	0	45	13	41
Cedar waxwing (*Bombycilla cedrorum*)	69	63	9	38	0	45	12	42
Other wood warblers	329	305	7	47	1	36	12	42
Red-winged blackbird (*Agelaius phoeniceus*)	61	57	7	53	2	30	12	42
Other vireos	50	46	8	40	0	45	11	45
Scissor-tailed flycatcher (*Tyrannus forficatus*)	51	47	8	41	0	45	11	46
American kestrel (*Falco sparverius*)	337	317	6	55	1	32	10	47
Chimney swift (*Chaetura pelagica*)	368	340	8	43	0	44	11	47
Red-eyed vireo (*Vireo olivaceus*)	104	96	8	42	0	45	11	47
Bats	505	471	7	51	1	37	11	50
Purple martin (*Progne subis*)	93	86	8	45	0	45	11	51
Other flycatchers	54	50	7	46	0	45	11	52
Wood thrush (*Hylocichla mustelina*)	28	26	7	48	0	45	10	53
Yellow-rumped Warbler (*Setophaga coronate*)	146	137	6	54	1	41	10	54

Species							
Western kingbird (*Tyrannus verticalis*)	45	42	7	52	0	45	10	55
Barn swallow (*Hirundo rustica*)	609	575	6	57	0	43	9	56
Killdeer (*Charadrius vociferous*)	434	412	5	60	1	40	8	56
Gray catbird (*Dumetella carolinensis*)	104	98	6	56	0	45	8	58
Horned lark (*Eremophila alpestris*)	850	814	4	67	1	35	8	59
Other sparrows	549	524	5	64	1	38	8	59
Cliff swallow (*Petrochelidon pyrrhonota*)	348	329	5	58	0	45	8	61
Bank swallow (*Riparia riparia*)	39	37	5	59	0	45	7	62
Savannah sparrow (*Passerculus sandwichensis*)	197	188	5	63	1	42	7	63
Upland sandpiper (*Bartramia longicauda*)	41	39	5	61	0	45	7	64
Indigo bunting (*Passerina cyanea*)	42	40	5	62	0	45	7	65
Hermit thrush (*Catharus guttatus*)	88	84	5	65	0	45	6	66
Ruby-throated hummingbird (*Archilochus colubris*)	45	43	4	66	0	45	6	67
Cardinals, grosbeaks, and allies	26	25	4	68	0	45	5	68
American pipit (*Anthus rubescens*)	60	58	3	69	0	45	5	69
Common yellowthroat (*Geothlypis trichas*)	61	59	3	70	0	45	5	70
Tree swallow (*Tachycineta bicolor*)	98	95	3	71	0	45	4	71
Common nighthawk (*Chordeiles minor*)	185	180	3	72	0	45	4	72
Baltimore oriole (*Icterus galbula*)	20	20	0	73	0	45	0	73
Dark-eyed junco (*Junco hyemalis*)	57	57	0	73	0	45	0	73

4 The composite rank represents the sum of the percentage of strikes with damage and the percentage of strikes with substantial damage for that species group. See
5 S1 Table for a list of species in each species group (i.e. Other ducks). Strike data are from separate databases maintained by the USN (1990-2017) and USAF
6 (1994-2017)

7 Table 6. Wildlife hazard rankings for 102 species groups from most to least hazardous for cargo aircraft within the U.S. (including
8 Alaska and Hawaii).
9

Species	Total strikes reported	Non damaging strikes	% with damage	Damage rank	% with substantial damage	Substantial damage rank	Relative hazard score	Composite rank
Snow goose (*Chen caerulescens*)	33	6	82	1	45	1	100	1
Canada goose (*Branta canadensis*)	43	17	60	2	33	2	73	2
Black vulture (*Coragyps atratus*)	275	111	60	3	26	3	67	3
Turkey vulture (*Cathartes aura*)	334	159	52	4	25	5	60	4
Double-crested cormorant (*Phalacrocorax auritus*)	26	14	46	6	23	6	54	5
Herring gull (*Larus argentatus*)	62	37	40	10	26	4	52	6
Swainson's hawk (*Buteo swainsoni*)	67	37	45	7	18	7	49	6
Mallard (*Anas platyrhynchos*)	123	65	47	5	11	12	46	8
Red-tailed hawk (*Buteo jamaicensis*)	369	217	41	8	15	9	45	8
Northern pintail (*Anas acuta*)	51	30	41	9	12	11	42	10
Great blue heron (*Ardea herodias*)	37	24	35	14	16	8	40	11
Pied-billed grebe (*Podilymbus podiceps*)	21	13	38	12	14	10	41	11
Other ducks	205	130	37	13	9	14	36	13
Osprey (*Pandion haliaetus*)	51	31	39	11	8	17	37	14
Common grackle (*Quiscalus quiscula*)	30	22	27	18	10	13	29	15
Other hawks	135	97	28	15	8	16	29	15
American coot (*Fulica americana*)	119	86	28	17	5	21	26	17
Great horned owl (*Bubo virginianus*)	48	36	25	19	6	20	25	18
Other falcons	39	31	21	21	8	18	22	18
Ring-billed gull (*Larus delawarensis*)	104	84	19	23	8	18	21	20
Other gulls	132	107	19	24	5	23	18	21
White-winged dove (*Zenaida asiatica*)	93	71	24	20	4	27	22	21
Rock dove (*Columba livia*)	188	156	17	26	5	22	17	23
Other blackbirds	24	21	13	37	8	15	16	24

Cattle egret (*Bubulcus ibis*)	46	39	15	28	4	25	15	25
White-throated swift (*Aeronautes saxatalis*)	112	96	14	30	4	24	15	26
Baltimore oriole (*Icterus galbula*)	53	45	15	29	4	29	15	27
European starling (*Sturnus vulgaris*)	175	153	13	36	3	30	13	28
Purple martin (*Progne subis*)	158	137	13	34	3	32	12	28
Yellow-billed cuckoo (*Coccyzus americanus*)	126	110	13	35	2	33	12	30
Brown-headed cowbird (*Molothrus ater*)	60	52	13	33	2	38	12	31
American crow (*Corvus brachyrhynchos*)	23	21	9	49	4	25	10	32
Ruby-throated hummingbird (*Archilochus colubris*)	57	50	12	38	2	36	11	32
Scarlet tanager (*Piranga olivacea*)	50	44	12	39	2	35	11	32
Gray catbird (*Dumetella carolinensis*)	219	189	14	31	1	49	11	35
Other terns	24	22	8	53	4	28	10	36
Northern flicker (*Colaptes auratus*)	32	23	28	16	0	68	22	37
American robin (*Turdus migratorius*)	551	497	10	45	2	40	9	38
Barn owl (*Tyto alba*)	47	43	9	52	2	34	8	39
Great crested flycatcher (*Myiarchus crinitus*)	39	36	8	56	3	31	8	40
Mourning dove (*Zenaida macroura*)	1624	1467	10	46	2	41	9	40
Other thrushes	307	272	11	41	1	46	10	40
Mississippi kite (*Ictinia mississippiensis*)	44	35	20	22	0	68	16	43
Cave swallow (*Petrochelidon fulva*)	70	64	9	50	1	43	8	44
Wood thrush (*Hylocichla mustelina*)	56	46	18	25	0	68	14	44
Brown thrasher (*Toxostoma rufum*)	30	25	17	27	0	68	13	46
American kestrel (*Falco sparverius*)	684	627	8	53	1	44	8	47
Yellow-bellied sapsucker (*Sphyrapicus varius*)	57	53	7	62	2	36	7	48
Black-bellied plover (*Pluvialis squatarola*)	37	32	14	32	0	68	11	49
Indigo bunting (*Passerina cyanea*)	69	64	7	60	1	42	7	50
Ovenbird (*Seiurus aurocapillus*)	109	101	7	59	1	48	6	51
Cardinals, grosbeaks, and allies	69	61	12	40	0	68	9	52
Meadowlarks	1040	974	6	71	2	39	6	53
Northern mockingbird (*Mimus polyglottos*)	44	39	11	42	0	68	9	53

Sora (*Porzana carolina*)	83	74	11	43	0	68	9	55
Other plovers	70	63	10	44	0	68	8	56
Coyote (*Canis latrans*)	22	20	9	47	0	68	7	57
Golden-crowned kinglet (*Regulus satrapa*)	22	20	9	47	0	68	7	57
Upland sandpiper (*Bartramia longicauda*)	70	64	9	50	0	68	7	59
Red-eyed vireo (*Vireo olivaceus*)	236	220	7	69	1	51	6	60
Other shorebirds	120	110	8	53	0	68	7	61
Bats	1114	1034	7	61	1	62	6	62
Hermit thrush (*Catharus guttatus*)	146	136	7	68	1	56	6	63
Red-winged blackbird (*Agelaius phoeniceus*)	108	102	6	78	1	47	5	64
Snow bunting (*Plectrophenax nivalis*)	40	37	8	57	0	68	6	64
Ruby-throated hummingbird (*Archilochus colubris*)	67	62	7	58	0	68	6	66
Killdeer (*Charadrius vociferous*)	914	862	6	77	1	50	5	67
Blue-gray gnatcatcher (*Polioptila caerulea*)	80	76	5	83	1	45	5	68
Other wood warblers	757	705	7	67	1	63	6	69
Common nighthawk (*Chordeiles minor*)	404	381	6	76	1	55	5	70
Other flycatchers	100	93	7	63	0	68	6	70
Barn swallow (*Hirundo rustica*)	1207	1136	6	74	1	58	5	72
Scissor-tailed flycatcher (*Tyrannus forficatus*)	115	107	7	64	0	68	5	72
Other longspurs	58	54	7	65	0	68	5	74
Other wrens	29	27	7	65	0	68	5	74
Tree swallow (*Tachycineta bicolor*)	170	160	6	74	1	59	5	74
Cedar waxwing (*Bombycilla cedrorum*)	179	168	6	73	1	61	5	77
Common yellowthroat (*Geothlypis trichas*)	133	126	5	80	1	54	5	77
Cliff swallow (*Petrochelidon pyrrhonota*)	729	682	6	70	0	65	5	79
Lapland longspur (*Calcarius lapponicus*)	81	76	6	72	0	68	5	80
American pipit (*Anthus rubescens*)	120	115	4	90	1	52	4	81
Dark-eyed junco (*Junco hyemalis*)	173	164	5	82	1	60	5	81
Chimney swift (*Chaetura pelagica*)	740	699	6	79	0	66	5	83
Horned lark (*Eremophila alpestris*)	1902	1819	4	89	1	57	4	84

American goldfinch (*Spinus tristis*)	38	36	5	80	0	68	4	85
Other doves	20	19	5	83	0	68	4	86
Western kingbird (*Tyrannus verticalis*)	121	118	2	98	1	53	3	86
Other sparrows	1310	1247	5	85	0	67	4	88
Bank swallow (*Riparia riparia*)	86	82	5	86	0	68	4	89
Bobolink (*Dolichonyx oryzivorus*)	45	43	4	87	0	68	3	90
Yellow-rumped Warbler (*Setophaga coronate*)	317	303	4	88	0	68	3	91
Common snipe (*Gallinago gallinago*)	50	48	4	91	0	68	3	92
Savannah sparrow (*Passerculus sandwichensis*)	470	456	3	95	0	64	3	92
Short-eared owl (*Asio flammeus*)	26	25	4	92	0	68	3	94
Dunlin (*Calidris alpine*)	27	26	4	93	0	68	3	95
Other vireos	112	108	4	94	0	68	3	96
House finch (*Haemorhous mexicanus*)	37	36	3	96	0	68	2	97
Least sandpiper (*Calidris minutilla*)	38	37	3	97	0	68	2	98
Wilson's snipe (*Gallinago delicate*)	45	44	2	99	0	68	2	99
Lesser nighthawk (*Chordeiles acutipennis*)	49	48	2	100	0	68	2	100
Burrowing owl (*Athene cunicularia*)	50	49	2	101	0	68	2	101

10 The composite rank represents the sum of the percentage of strikes with damage and the percentage of strikes with substantial damage for that species group. See
11 S1 Table for a list of species in each species group (i.e. Other ducks). Strike data are from separate databases maintained by the USN (1990-2017) and USAF
12 (1994-2017).

13 Table 7. Wildlife hazard rankings for 15 species groups from most to least hazardous for stealth aircraft within the U.S. (including
14 Alaska and Hawaii).

15

Species	Total strikes reported	Non damaging strikes	% with damage	Damage rank	% with substantial damage	Substantial damage rank	Relative hazard score	Composite rank
Turkey vulture (*Cathartes aura*)	21	11	48	1	10	1	100	1
Common nighthawk (*Chordeiles minor*)	23	21	9	5	4	2	23	2
American robin (*Turdus migratorius*)	25	23	8	7	4	3	21	3
Mourning dove (*Zenaida macroura*)	90	82	9	3	1	7	18	3
Savannah sparrow (*Passerculus sandwichensis*)	22	20	9	2	0	8	16	3
Bats	45	41	9	3	0	8	16	6
Killdeer (*Charadrius vociferous*)	43	40	7	9	2	4	16	7
Barn swallow (*Hirundo rustica*)	60	55	8	6	0	8	15	8
Horned lark (*Eremophila alpestris*)	83	77	7	8	1	6	15	8
Other sparrows	69	67	3	12	1	5	8	10
Meadowlarks	56	54	4	10	0	8	6	11
Cliff swallow (*Petrochelidon pyrrhonota*)	31	30	3	11	0	8	6	12
Other wood warblers	35	34	3	13	0	8	5	13
American kestrel (*Falco sparverius*)	40	39	3	14	0	8	4	14
Chimney swift (*Chaetura pelagica*)	34	34	0	15	0	8	0	15

16 The composite rank represents the sum of the percentage of strikes with damage and the percentage of strikes with substantial damage for that species group. See
17 S1 Table for a list of species in each species group (i.e. Other ducks). Strike data are from separate databases maintained by the USN (1990-2017) and USAF
18 (1994-2017)

19

20

Median body mass for avian species involved in damaging strikes was 33 g. There were

seven species in our dataset of which all reported strikes were non-damaging and their median

body mass was 19 g. There was a strong positive quadratic relationship between the relative

hazard score and avian body mass for the species groups involved in bird strikes with all military

fixed-wing aircraft ($r^2 = 0.77$). The quadratic curve was steeper for the fighter airframe with a

higher y-intercept, compared to the cargo trend (Figure 2, Supplemental Table 4).
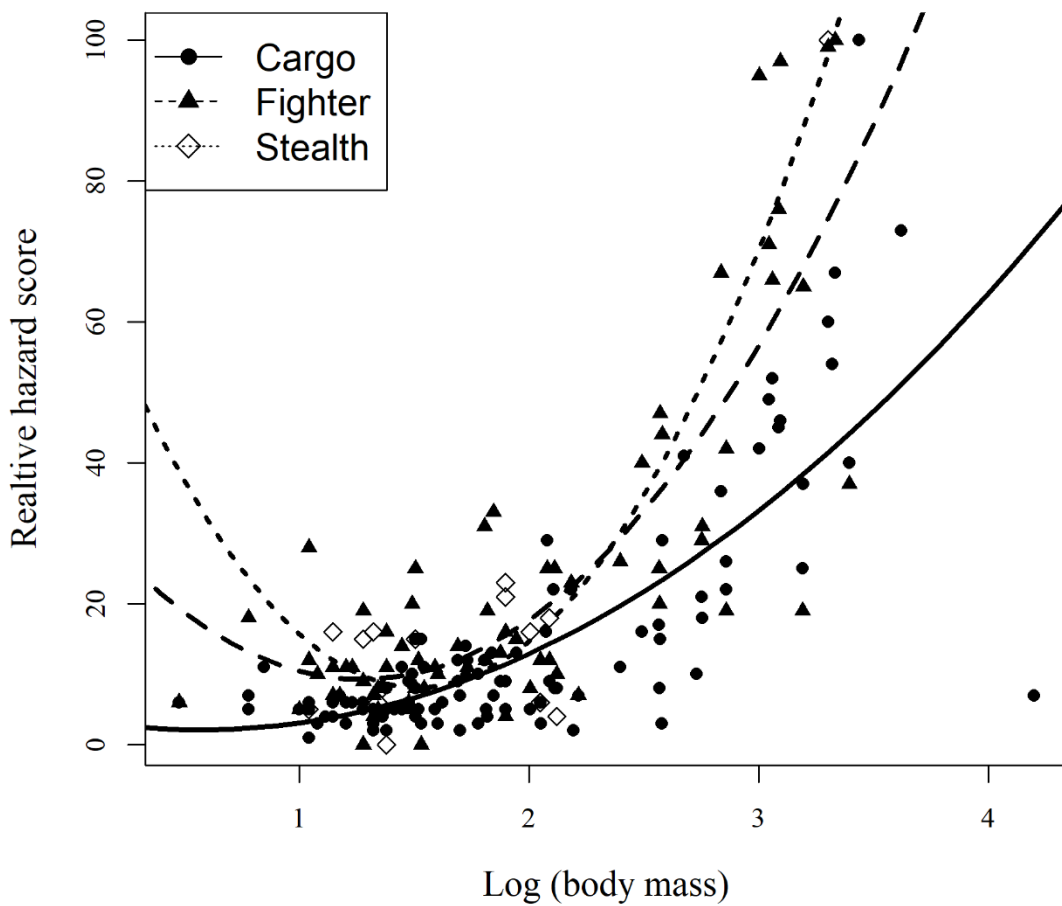
Figure 2. Relationship between avian body mass and relative hazard score for avian groups with military stealth, fighter, and cargo airframes. Only strikes identified to species and occurred within the U.S. were included. All airframes included those not singled out in the airframe analysis (i.e. rotorcraft, propeller aircraft). Strike data are from separate databases maintained by the U.S. Navy (1990-2017) and U.S. Air Force (1994-2017).

V.   Conclusion

We found that wildlife hazards to military aviation differs from civil aviation. Species relative hazard scores were higher for military than civil aircraft. Furthermore, we found differences in relative hazard scores among airframe types. Similar to other studies, birds associated with water were ranked as most hazardous (Dolbeer, Wright et al. 2000, Zakrajsek and Bissonette 2005, DeVault, Belant et al. 2011, DeVault, Blackwell et al. 2016), as well as raptors (Dolbeer, Wright et al. 2000, Zakrajsek and Bissonette 2005, DeVault, Belant et al. 2011), and large mammals (DeVault, Belant et al. 2011, Schwarz, Belant et al. 2014). For the combined USAF and USN datasets, there was a strong quadratic trend between avian body mass and relative hazard score. As avian body mass increased, so too did the relative hazard score, as observed in similar studies (DeVault, Belant et al. 2011). This significant trend can be used to calculate relative hazard scores for species not in our dataset.

Predicted relative hazard values were higher for fighter and stealth than cargo airframes. It is likely that higher speeds and lower flight altitudes of fighter airframes, versus cargo aircraft contribute to higher relative hazard scores. Furthermore, the radar absorbing skin of stealth airframes may also contribute to higher relative hazard scores. Alternatively, cargo airframes are similar to civil aviation in terms of design and flight patterns, with long ascends and descents and high cruising altitudes (Dolbeer, Wright et al. 2000, Zakrajsek and Bissonette 2005). It is unclear why the USN experienced higher hazard scores than the USAF. Some possible explanations included differences in strike reporting rates, fewer strikes identified to species level in the USN dataset, and perhaps differences in mission types between the two military branches. Interestingly, there were few Class A and B USN strikes that were identified to species level during the time period examined.

These results, coupled with data on species seasonal relative abundance on and near airfields, will be important in directing airfield management (DeVault, Belant et al. 2011). Specifically, data on species relative abundance can be combined with relative hazard scores to prioritize wildlife management on airfields (Blackwell, Seamans et al. 2013). Also, depending on the airfield, hazard scores can be calculated per airframe type. For example, if an airfield is primarily used for fighter mission/training, the fighter airframe relative hazard scores should be used. This would ensure that species on the airfield would be prioritized based on the severity of the strike specific to that airframe. Ultimately, the development of airframe-specific strike risk metrics will yield more accurate information on airframe vulnerability to strike by mission type.

VI.   Acknowledgements

VII.   References

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VIII. Supplemental information

Supplemental Table 1. Wildlife species ($n = 204$) involved in more than 20 strikes with military

aircraft grouped into 112 species groups.

Supplemental Table 2. Definitions of military damage classes.

Supplemental Table 3. Airframe types ($n = 189$) involved in wildlife strikes with military aircraft grouped into eight airframe groups.

Supplemental Table 4. Significant fitted quadratic trend line equations for military airframes describing the relationship between relative hazard score and avian body mass.

Supplemental Table 1. Wildlife species (*n* = 196) involved in more than 20 strikes with military aircraft grouped into 112 species groups.

Acadian flycatcher	Other flycatchers
American coot	American coot
American crow	American crow
American golden-plover	Other plovers
American goldfinch	American goldfinch
American kestrel	American kestrel
American pipit	American pipit
American redstart	Other wood warblers
American robin	American robin
American tree sparrow	Other sparrows
American wigeon	Other ducks
American woodcock	Other shorebirds
Baird's sandpiper	Other shorebirds
Bald eagle	Bald eagle
Baltimore oriole	Baltimore oriole
Bank swallow	Bank swallow
Barn owl	Barn owl
Barn swallow	Barn swallow
Bay-breasted warbler	Other wood warblers
Big brown bat	Bats
Black tern	Other terns
Black vulture	Black vulture
Black-and-white warbler	Other wood warblers
Black-bellied plover	Black-bellied plover
Blackburnian warbler	Other wood warblers

Blackpoll warbler	Other wood warblers
Black-throated blue warbler	Other wood warblers
Black-throated green warbler	Other wood warblers
Black-throated sparrow	Other sparrows
Blue-gray gnatcatcher	Blue-gray gnatcatcher
Blue-headed vireo	Other vireos
Blue-winged teal	Other ducks
Bobolink	Bobolink
Brazilian free-tailed bat	Bats
Brewer's blackbird	Other blackbirds
Brewer's sparrow	Other sparrows
Broad-winged hawk	Other hawks
Brown thrasher	Brown thrasher
Brown-headed cowbird	Brown-headed cowbird
Buff-breasted sandpiper	Other shorebirds
Burrowing owl	Burrowing owl
California gull	Other gulls
Canada goose	Canada goose
Canada warbler	Other wood warblers
Cape may warbler	Other wood warblers
Cassin's sparrow	Other sparrows
Cattle egret	Cattle egret
Cave swallow	Cave swallow
Cedar waxwing	Cedar waxwing
Chestnut-collared longspur	Other longspurs
Chestnut-sided warbler	Other wood warblers
Chimney swift	Chimney swift
Chipping sparrow	Other sparrows
Clay-colored sparrow	Other sparrows

Cliff swallow	Cliff swallow	Gray catbird	Gray catbird
Common grackle	Common grackle	Gray-cheeked thrush	Other thrushes
Common ground dove	Other doves	Great blue heron	Great blue heron
Common loon	Common loon	Great crested flycatcher	Great crested flycatcher
Common nighthawk	Common nighthawk	Great egret	Other egrets
Common snipe	Common snipe	Great horned owl	Great horned owl
Common yellowthroat	Common yellowthroat	Great-tailed grackle	Other blackbirds
Coopers hawk	Other hawks	Green-winged teal	Other ducks
Coyote	Coyote	Green heron	Green heron
Dark-eyed junco	Dark-eyed junco	Hermit thrush	Hermit thrush
Dickcissel	Cardinals, grosbeaks, and allies	Herring gull	Herring gull
		Hoary bat	Bats
Double-crested cormorant	Double-crested cormorant	Hooded warbler	Other wood warblers
Dunlin	Dunlin	Horned lark	Horned lark
Eastern bluebird	Other thrushes	House finch	House finch
Eastern kingbird	Other flycatchers	House sparrow	Other sparrows
Eastern meadowlark	Meadowlarks	House wren	House wren
Eastern pipistrelle	Bats	Indigo bunting	Indigo bunting
Eastern towhee	Other sparrows	Killdeer	Killdeer
Eastern wood-pewee	Other flycatchers	Lapland longspur	Lapland longspur
Eurasian collared dove	Other doves	Lark bunting	Other sparrows
European starling	European starling	Lark sparrow	Other sparrows
Evening bat	Bats	Laughing gull	Other gulls
Ferruginous hawk	Other hawks	Least flycatcher	Other flycatchers
Field sparrow	Other sparrows	Least sandpiper	Least sandpiper
Fox sparrow	Other sparrows	Least tern	Other terns
Franklin's gull	Other gulls	Leconte's sparrow	Other sparrows
Gadwall	Other ducks	Lesser nighthawk	Lesser nighthawk
Golden-crowned kinglet	Golden-crowned kinglet	Lesser scaup	Other ducks
Grasshopper sparrow	Other sparrows	Lincoln's sparrow	Other sparrows

Magnolia warbler	Other wood warblers
Mallard	Mallard
Marsh wren	Other wrens
Mccown's longspur	Other longspurs
Merlin	Other falcons
Mississippi kite	Mississippi kite
Mourning dove	Mourning dove
Nashville warbler	Other wood warblers
Northern flicker	Northern flicker
Northern harrier	Other hawks
Northern mockingbird	Northern mockingbird
Northern parula	Other wood warblers
Northern pintail	Northern pintail
Northern shoveler	Other ducks
Northern waterthrush	Other wood warblers
Northern yellow bat	Bats
Orange-crowned warbler	Other wood warblers
Orchard oriole	Orchard oriole
Osprey	Osprey
Ovenbird	Ovenbird
Pacific golden plover	Other plovers
Pacific-slope flycatcher	Other flycatchers
Palm warbler	Other wood warblers
Pectoral sandpiper	Other shorebirds
Peregrine falcon	Other falcons
Pied-billed grebe	Pied-billed grebe
Pine warbler	Other wood warblers
Prairie warbler	Other wood warblers
Purple martin	Purple martin
Red bat	Bats

Red-eyed vireo	Red-eyed vireo
Red-shouldered hawk	Other hawks
Red-tailed hawk	Red-tailed hawk
Red-winged blackbird	Red-winged blackbird
Ring-billed gull	Ring-billed gull
Rock dove	Rock dove
Rose-breasted grosbeak	Cardinals, grosbeaks, and allies
Ruby-crowned kinglet	Ruby-crowned kinglet
Ruby-throated hummingbird	Ruby-throated hummingbird
Ruddy duck	Other ducks
Sage sparrow	Other sparrows
Savannah sparrow	Savannah sparrow
Scarlet tanager	Scarlet tanager
Scissor-tailed flycatcher	Scissor-tailed flycatcher
Seminole bat	Bats
Semipalmated plover	Other plovers
Semipalmated sandpiper	Semipalmated sandpiper
Sharp-shinned hawk	Other hawks
Short-eared owl	Short-eared owl
Silver-haired bat	Bats
Smith's longspur	Other longspurs
Snow bunting	Snow bunting
Snow goose	Snow goose
Song sparrow	Other sparrows
Sora	Sora
Sprague's pipit	Sprague's pipit
Swainson's hawk	Swainson's hawk
Swainson's thrush	Other thrushes

Swamp sparrow	Other sparrows

Tennessee warbler	Other wood warblers
Townsends warbler	Other wood warblers
Tree swallow	Tree swallow
Turkey vulture	Turkey vulture
Upland sandpiper	Upland sandpiper
Vaux's swift	Vaux's swift
Veery	Other thrushes
Vesper sparrow	Other sparrows
Violet-green swallow	Violet-green swallow
Warbling vireo	Other vireos
Western kingbird	Western kingbird
Western meadowlark	Meadowlarks
Western sandpiper	Other shorebirds
Western tanager	Cardinals, grosbeaks, and allies
White-crowned sparrow	Other sparrows
White-eyed vireo	Other vireos
White-tailed deer	White-tailed deer
White-throated sparrow	Other sparrows
White-throated swift	White-throated swift
White-winged dove	White-winged dove
Wilson's snipe	Wilson's snipe
Wilson's warbler	Other wood warblers
Winter wren	Other wrens
Wood duck	Other ducks

Supplemental Table 2. Definitions of military damage classes.

Damage Class	Associated monetary Cost
A	> $2,000,000
B	$500,000 – $2,000,000
C	$50,000 – $500,000
D	$20,000 – $50,000
E	< $50,000
H (damaging)	> $56
H (non-damaging)	≤ $55

Supplemental Table 3. Airframe types (n = 189) involved in wildlife strikes with military aircraft grouped into 8 airframe groups.

Airframes with * indicate airframes that could have multiple classifications. For our purposes we grouped airframes by mission type.

Airframe	Airframe group
C-130	heavy
C-135	heavy
C-17	heavy
F-16	fighter
T-38	fighter
T-1	fighter
A-10	heavy
F-15	fighter
C-5	heavy
KC-10	heavy
T-6	fighter
T045C	fighter
B-52	heavy
B-2	stealth
T-37	fighter
C-21	heavy
E-8	heavy
B-1*	stealth
H-60	rotorcraft
F-22	fighter
TC012B	fighter
F018F	fighter
H-1	rotorcraft
P008A	heavy
P003C	heavy
T006B	propeller/small
E-3	heavy
F018E	fighter
E-4	heavy
C-141	heavy
T034C	propeller/small
F018C	fighter
C-40	heavy
V-22	heavy/rotorcraft
C-9	heavy
C-32	heavy
TH057C	rotorcraft
MH060S	rotorcraft
C-12	propeller/small
MH060R	rotorcraft
T045A	rotorcraft
T044C	propeller/small
E006B	heavy
T044A	propeller/small
C-37	propeller/small
MV022B	heavy/rotorcraft
F-35*	fighter
EA006B	heavy
T006A	propeller/small
KC130J	heavy
U-2*	stealth
C-20	heavy

U-28	propeller/small	UH001Y	rotorcraft
H-53	rotorcraft	F-18	fighter
C-146	propeller/heavy	Q-9	propeller/heavy
EA018G	fighter	F018B	fighter
SH060B	rotorcraft	SH060F	rotorcraft
T-43	heavy	C130A	propeller/heavy
E002C+	propeller/heavy	CRJ	heavy
T039N	fighter	F015C	fighter
F005N	fighter	F035C	fighter
T-53	rotorcraft	OTHER	other
F018D	fighter	C-27	propeller/heavy
F-117	stealth	Q-4*	stealth
C026	propeller/small	NP003D	propeller/heavy
CH053E	rotorcraft	TH057B	rotorcraft
C040A	heavy	UC012B	propeller/heavy
E002C	heavy/rotorcraft	E-9	propeller/heavy
AV008B	fighter	UV-18	propeller/heavy
C130T	propeller/heavy	T-41	propeller/heavy
C-26	propeller/small	C130F	propeller/heavy
E002D	heavy/rotorcraft	F018A	fighter
F-4	fighter	KC130F	propeller/heavy
C002A	propeller/heavy	MH053E	rotorcraft
C-145	propeller/small	F-111	fighter
C009B	heavy	CC	heavy
F018	fighter	CH046E	rotorcraft
AH001W	rotorcraft	F005F	fighter
F018A+	fighter	TAV008B	fighter
T038C	fighter	AL-1	heavy
T044	propeller/small	C-38	heavy
F035B	stealth	E-6	heavy

C130	propeller/heavy	CP	other
F016A	fighter	EP003	propeller/heavy
F016C	fighter	F016	fighter
T039G	heavy	F016B	fighter
C-18	heavy	F016N	fighter
EXEC/CORP	other	HH060H	rotorcraft
T-3	propeller/small	UH001N	rotorcraft
TG-10	propeller/heavy	UH003H	rotorcraft
TG-16	propeller/heavy	C-150	propeller/small
AH001Z	rotorcraft	DA-20	propeller/small
C017A	heavy	PA-32	propeller/small
C035D	heavy	T-39	heavy
C130J	propeller/heavy	TG-7	propeller/small
HH065	rotorcraft	A004F	fighter
KC130T	propeller/heavy	AV008	fighter
P003	propeller/heavy	B200	propeller/small
S003B	fighter	BA146	heavy
T006	propeller/small	BO747	heavy
T039D	heavy	C009	heavy
UH060L	rotorcraft	C012B	propeller/small
C-137	heavy	C012C	propeller/small
C-22	heavy	C012F	propeller/small
T-51	propeller/small	C017	heavy
T-52	propeller/small	C020G	heavy
AH001	rotorcraft	C040	heavy
BO707	heavy	CH046	rotorcraft
C012	propeller/small	EC130J	propeller/heavy
C020D	heavy	F015D	fighter
C026A	propeller/small	F022A	fighter
C130H	propeller/heavy	F035A	fighter

HH001N	rotorcraft
HH060	rotorcraft
HH065A	rotorcraft
KC135T	heavy
NC-12B	propeller/small
S003	fighter
UC012F	propeller/small
UC012M	propeller/small
VH060N	rotorcraft
C-25	propeller/small
Q-1	other
TG-14	other
OTHER	other
Aerostat	other
UNKNOWN	other
Private	other
Raven	other

Supplemental Table 4. Significant fitted quadratic trend line equations for military airframes describing the relationship between relative hazard score and avian body mass.

Airframe	Equation	r^2
Stealth	$Y = 73.22 - 85.80 + 28.26X^2$	0.89
Cargo	$Y = 3.79 - 5.97 + 5.26X^2$	0.58
Fighter	$Y = 34.97 - 40.40 + 15.87X^2$	0.69
All military fixed-wing	$Y = 25.26 - 29.59 + 11.19X^2$	0.77

IX. **Appendix A**

1.0 Navy data processing

```
# Strike data processing

# Preamble - Load libraries and clear environments

library(knitr)
remove(list=ls())

# Step 1. Load Cotterell older data. Data sent to Travis in March 2017.

Cotterell<-read.csv('Cotterell - BASH Costs 1990-2017.csv',header= TRUE)
Cotterell$HT_ID <- format(Cotterell$HT_ID, scientific = FALSE)

# Step 2. Only keep certain columns.

df = subset(Cotterell, select = c(RPRTBL_EVENT_SERL,
      HT_ID,EVENT_DATE,EVENT_SEVTY_C,RPRTG_UIC,ACFT_MODEL,BUNO_FAA_IDN,
      ACFT_DMG_COST,SPECIES_SERL,SPECIES_C,SPECIES,SPECIES_GRP_C,SPECIES_GRP,
      SPECIES_TYP_C,SPECIES_TYP,DMG_CMTS,EVENT_NARR,INVLVD_FAC_NARR))

# Step 3. Create a ALT and TIME column to match other dataset.

df$EVENT_TIME<-'NA'
df$ALT_AGL<-'None'

# Step 4. Estimate the damage cost per year.


costs<-which(is.na(df$ACFT_DMG_COST))
df.1<-df[-costs,]
a<-sum(df.1$ACFT_DMG_COST)
a

## [1] 515950728

a/26

## [1] 19844259

# Step 5. Load Smithsonian data. Took 'updated species' from the WESS spread
sheet (no color) and not matched records (light green).

Smithsonian<-read.csv("Book3.csv",header=TRUE)
Smithsonian$HT_ID <- format(Smithsonian$HT_ID, scientific = FALSE)

# Step 6. Update species by matching WESS number (HT_ID).

df<-as.data.frame(df[!duplicated(df$HT_ID), ])
Smithsonian<-as.data.frame(Smithsonian[!duplicated(Smithsonian$HT_ID), ])
```

```r
df2<-data.frame(df,
                ID<-data.frame(ID=Smithsonian$Update.ID.to.[pmatch(df$HT_ID,S
mithsonian$HT_ID,duplicates.ok = FALSE)]))

# Step 7.Replace species ID with the correct ID, if applicable.

matched<-read.csv("matched.csv")

matched$true.ID<-"NA"

matched$ID[is.na(matched$ID)] <- "None"

matched$SPECIES<-as.character(matched$SPECIES)
matched$ID<-as.character(matched$ID)

matched$true.ID<-ifelse(matched$ID =="None",matched$SPECIES,matched$ID)

# Step 8. Save the data.

nrow(matched)

## [1] 12490

save(matched,file = "matched_navy_strikes.Rdata")
write.csv(matched,'matched_navy_strikes.csv')
```

1.1 More data processing

```r
# Strike data processing

# Preamble - Load libraries and clear environments
library(knitr)
remove(list=ls())

# Step 1. Load combined military strikes. Start with 12,490 records.
## Note at I change NA to 0 for costs
matched<-read.csv('matched_navy_strikes.csv')
nrow(matched)

## [1] 12490

matched<-matched[!(is.na(matched$true.ID) | matched$true.ID==""), ]

# Step 2. Remove all unknowns. Down to 4,656 records.

unk<-which(matched$true.ID=="BAT"|matched$true.ID=="bat?"||matched$true.ID=="
No feather material found"|matched$true.ID=="delete 1 of the Dickcissel"| mat
ched$true.ID=="delete this species"|matched$true.ID=="DEER"|matched$true.ID==
"duplicate?"|
matched$true.ID=="FOX"|matched$true.ID=="insect"| matched$true.ID=="insect "|
matched$true.ID=="LIZARD"|matched$true.ID=="no feather material found"|matche
d$true.ID=="no feather remains found"|matched$true.ID=="SEABIRD"|matched$true
.ID=="SHOREBIRD"|
matched$true.ID=="SNAKE"|matched$true.ID=="SONGBIRD"|
matched$true.ID=="UNKNOWN WATERFOWL"|matched$true.ID=="SHOREBIRD"|
matched$true.ID=="UNKNOWN WADINGBIRD"|matched$true.ID=="UNKNOWN SONGBIRD"|
matched$true.ID=="UNKNOWN SHOREBIRD"|matched$true.ID=="UNKNOWN SEABIRD"|
matched$true.ID=="UNKNOWN RAPTOR"|matched$true.ID=="UNKNOWN OTHER"|
matched$true.ID=="UNKNOWN GAMEBIRD"|matched$true.ID=="UNKNOWN BIRD GROUP"|
matched$true.ID=="UNKNOWN BIRD"|matched$true.ID=="UNKNOWN ANIMAL"|
matched$true.ID=="UNKNOWN"|matched$true.ID=="UNIDENTIFIED GULL"|
matched$true.ID=="undetermined Zonotrichia sparrow"|matched$true.ID=="undeter
mined woodpecker"|
matched$true.ID=="undetermined warbler"|matched$true.ID=="undetermined Vesper
bat"|matched$true.ID=="undetermined thrush"|matched$true.ID=="undetermined sw
ift"|matched$true.ID=="undetermined swallow "|matched$true.ID=="undetermined
swallow"|
matched$true.ID=="undetermined sparrow"|matched$true.ID=="undetermined pigeon
"|matched$true.ID=="UNDETERMINED SONGBIRD"|matched$true.ID=="undetermined mou
se-tailed bat"|
matched$true.ID=="undetermined sandpiper"|matched$true.ID=="undetermined rapt
or"|matched$true.ID=="undetermined rail"|matched$true.ID=="undetermined plove
r"|matched$true.ID=="undetermined passerine"|matched$true.ID=="undetermined o
ld world pipistrelle bat"|
matched$true.ID=="undetermined old world pipistrelle"|matched$true.ID=="undet
```

```
ermined nighthawk"|
matched$true.ID=="undetermined hummingbird"|matched$true.ID=="undetermined he
ron"|matched$true.ID=="undetermined hairy-tailed bat"|matched$true.ID=="undet
ermined grebe"|matched$true.ID=="undetermined free-tailed bat"|matched$true.I
D=="undetermined flycatcher"|
matched$true.ID=="undetermined falcon"|matched$true.ID=="undetermined dove"|
matched$true.ID=="undetermined diving duck"|matched$true.ID=="undetermined da
bbling duck"|matched$true.ID=="undetermined cuckoo"|matched$true.ID=="undeter
mined bird & Rabbit"|
matched$true.ID=="undetermined bat"|matched$true.ID=="undetermined Aechmophor
us grebe"|matched$true.ID=="undeteremined vesper bat"|
matched$true.ID=="UNDETERMINED FALCON"|matched$true.ID=="UNDETERMINED PASSERI
NE"|matched$true.ID=="undetermined vesper bat"|
matched$true.ID=="unidentified gull"|matched$true.ID=="unknown bird"|matched$
true.ID=="undetermined vesper bat"|
matched$true.ID=="unknown raptor"|matched$true.ID=="unknown waterfowl"|matche
d$true.ID=="undetermined vesper bat"|
matched$true.ID=="undetermined vesper bat"|
matched$true.ID=="BAT"|matched$true.ID=="bat?"|matched$true.ID=="No feather m
aterial found"|matched$true.ID=="WATERFOWL"|
matched$true.ID=="SQUIRREL"|matched$true.ID=="MOUSE"|
matched$true.ID=="Insect")

matched.2 <-matched[-unk,]
nrow(matched.2)

## [1] 4656

species.1<-as.data.frame(table(matched.2$true.ID))

# Step 4. Load Brooks data to match country locations.

countryFilter<-read.csv("Brooks - BASH 2007-Present.csv",header=T)

# Step 5. Match country locations.

df.5<-data.frame(matched.2,
                 country<-data.frame(country=countryFilter$CNTRY
                     [match(matched.2$RPRTBL_EVENT_SERL,
                            countryFilter$RPRTBL_EVENT_SERL)]))
df.6<-data.frame(df.5,
                 state<-data.frame(state=countryFilter$STATE_PROV
                     [match(df.5$RPRTBL_EVENT_SERL,
                            countryFilter$RPRTBL_EVENT_SERL)]))
df.7<-data.frame(df.6,
                 state<-data.frame(state=countryFilter$STATE_PROV
                     [match(df.6$RPRTBL_EVENT_SERL,
                            countryFilter$RPRTBL_EVENT_SERL)]))
df.7<-data.frame(df.7,
                 time<-data.frame(time=countryFilter$EVENT_TIME
```

```r
                    [match(df.7$RPRTBL_EVENT_SERL,
                           countryFilter$RPRTBL_EVENT_SERL)]))

# Step 6. Filter to only include records in the United States.
# Down to 4,436 records.
U.S.<-which(df.7$country==" UNITED STATES")
df.8 <-df.7[U.S.,]
nrow(df.8)

## [1] 4436

# Step 7. Remove Wake Island and Midway Island.

remove.state<-which(df.8$state=="MIDWAY ISLAND"|
        df.8$state=="WAKE ISLAND")
df.9 <-df.8[-remove.state,]
nrow(df.9)

## [1] 4433

# Step 8. For Navy data split Class H up. Damage costs less than $55 will be
considered non-damaging.

remove<-which(df.9$EVENT_SEVTY_C =="H")

just.h<-df.9[remove,]

just.h$ACFT_DMG_COST<-as.numeric(just.h$ACFT_DMG_COST)

just.h$EVENT_SEVTY_C<-ifelse(just.h$ACFT_DMG_COST <= 55 ,"No Data","H")

just.h$EVENT_SEVTY_C[is.na(just.h$EVENT_SEVTY_C)] <- "No Data"

df<-df.9[-remove,]

df.9<-rbind(df,just.h)

# Step 9. Read USAF data.

USAF<-read.csv("USDA APHIS request (12 JAN 2018 1406(Z)).csv")
names(USAF)

##  [1] "Event.Report.Number"
##  [2] "Event.Date..Local"
##  [3] "Event.Class.Flagword"
##  [4] "One.liner"
##  [5] "Event.Duty.Status"
##  [6] "Event.Time..Local"
##  [7] "Total.Event.Cost..Excluding.Injury.Cost."
##  [8] "Total.Event.Cost.with.Injuries"
##  [9] "Nearest.Base"
## [10] "Nearest.Airfield"
```

```
## [11] "U.S..State"
## [12] "Altitude"
## [13] "Altitude.Level"
## [14] "Altitude.Unable.to.Determine."
## [15] "Phase.of.Ops.Tier.1"
## [16] "Phase.of.Ops.Tier.2"
## [17] "Airspeed"
## [18] "General.MDS.Grouping"
## [19] "Order..common.name."
## [20] "Species..common.name."
## [21] "Impact.Point"

costs<-subset(USAF,Total.Event.Cost.with.Injuries>0)
a<-sum(costs$Total.Event.Cost.with.Injuries)
a

## [1] 865631327

a/23

## [1] 37636145

# Step 10. Subset to contain certain fields. Remove any blank species records
.

USAF.2 = subset(USAF, select = c(Event.Report.Number,Event.Date..Local,
      Event.Class.Flagword,Event.Time..Local,Total.Event.Cost.with.Injuries,N
earest.Base,Nearest.Airfield,
U.S..State,Altitude,General.MDS.Grouping,Order..common.name.,
      Species..common.name.,Impact.Point))

USAF.3<-USAF.2[!with(USAF.2,is.na(Species..common.name.)),]

# Step 11. Create two dataframes one based on state known and the other state
# unknown.

remove2<-which(USAF.3$U.S..State=="No Data")

USAF.4 <-USAF.3[remove2,]

remove3<-which(USAF.3$U.S..State=="No Data")

USAF.5 <-USAF.3[-remove3,]

# Step 12. Manually keep bases that are in the US, but state was "No Data".

remove4<-which(USAF.4$nearest.base=="Hurlburt Field"|
USAF.4$nearest.base=="Altus AFB"|USAF.4$nearest.base=="Randolph AFB"|
USAF.4$nearest.base=="McGuire AFB"|USAF.4$nearest.base=="Vance AFB"|
USAF.4$nearest.base=="Laughlin AFB"|USAF.4$nearest.base=="Barksdale AFB"|USAF
.4$nearest.base=="McConnell AFB"|USAF.4$nearest.base=="Whiteman AFB"|USAF.4$n
```

```
earest.base=="Grand Forks AFB"|USAF.4$nearest.base=="Luke AFB"|USAF.4$nearest
.base=="Seymour Johnson AFB"|
USAF.4$nearest.base=="Little Rock AFB"|USAF.4$nearest.base=="Tinker AFB"|USAF
.4$nearest.base=="Tyndall AFB"|USAF.4$nearest.base=="Charleston AFB"|USAF.4$n
earest.base=="Nellis AFB"|USAF.4$nearest.base=="Edwards AFB"|
USAF.4$nearest.base=="Pope Field"|USAF.4$nearest.base=="Robins AFB"|
USAF.4$nearest.base=="Fairchild AFB"|USAF.4$nearest.base=="Ellsworth AFB"|USA
F.4$nearest.base=="Mountain Home AFB"|USAF.4$nearest.base=="Eglin AFB"|USAF.4
$nearest.base=="Scott AFB"|USAF.4$nearest.base=="Sheppard AFB"|
USAF.4$nearest.base=="Shaw AFB"|USAF.4$nearest.base=="Offutt AFB"|
USAF.4$nearest.base=="Columbus AFB"|USAF.4$nearest.base=="Grissom ARB"|USAF.4
$nearest.base=="Wright-Patterson AFB"|
USAF.4$nearest.base=="Youngstown-Warren RAP ARS"|
USAF.4$nearest.base=="Kirtland AFB"|USAF.4$nearest.base=="Moody AFB"|
USAF.4$nearest.base=="Dyess AFB"|USAF.4$nearest.base=="Eielson AFB"|
USAF.4$nearest.base=="Holloman AFB"|USAF.4$nearest.base=="Minot AFB"|
USAF.4$nearest.base=="Westover ARB"|USAF.4$nearest.base=="Cannon AFB"|
USAF.4$nearest.base=="Elmendorf AFB"|USAF.4$nearest.base=="McChord AFB"|
USAF.4$nearest.base=="Minneapolis-St. Paul IAP ARS"|
USAF.4$nearest.base=="Beale AFB"| USAF.4$nearest.base=="Dover AFB"|
USAF.4$nearest.base=="Hill AFB"|
USAF.4$nearest.base=="March ARB"|USAF.4$nearest.base=="Bradley IAP ANG"|
USAF.4$nearest.base=="Francis S Gabreski IAP ANG"|
USAF.4$nearest.base=="Andrews AFB"| USAF.4$nearest.base=="Bangor IAP ANG"|
USAF.4$nearest.base=="Duke Field"|
USAF.4$nearest.base=="Hector IAP ANG"|
USAF.4$nearest.base=="Joint Base McGuire-Dix-Lakehurst"|
USAF.4$nearest.base=="Niagara Falls IAP ARS"|
USAF.4$nearest.base=="Travis AFB"| USAF.4$nearest.base=="Tucson IAP ANG"|USAF
.4$nearest.base=="Dobbins ARB"| USAF.4$nearest.base=="Keesler AFB"|USAF.4$nea
rest.base=="Charlotte/Douglas IAP ANG"|
USAF.4$nearest.base=="Cheyenne MAP ANG"|USAF.4$nearest.base=="Minot AFB"|
USAF.4$nearest.base=="Holloman AFB"|
USAF.4$nearest.base=="Crater Lake - Klamath RAP (Kingsley Field) ANG"|
USAF.4$nearest.base=="General Mitchell IAP ANG"|
USAF.4$nearest.base=="Hancock Field ANG"|
USAF.4$nearest.base=="Joe Foss Field ANG"|
USAF.4$nearest.base=="Patrick AFB"| USAF.4$nearest.base=="Pease ANGB"|USAF.4$
nearest.base=="Reno-Tahoe IAP ANG"|
USAF.4$nearest.base=="Salt Lake City IAP ANG"|
USAF.4$nearest.base=="Selfridge ANG"|
USAF.4$nearest.base=="Chicago/Ohare IAP IL"|
USAF.4$nearest.base=="Fort Smith MAP ANG"|
USAF.4$nearest.base=="Hickam AFB"|
USAF.4$nearest.base=="Joint Base Andrews-Naval Air Facility"|
USAF.4$nearest.base=="Joint Base Pearl Harbor-Hickam"|
USAF.4$nearest.base=="Langley AFB"| USAF.4$nearest.base=="MacDill AFB"|
USAF.4$nearest.base=="Majors Airport"|
USAF.4$nearest.base=="Atlantic City IAP ANG CGAS"|
USAF.4$nearest.base=="Capital MAP ANG"|
```

```r
USAF.4$nearest.base=="Channel Islands ANG"|
USAF.4$nearest.base=="Des Moines IAP ANG"|
USAF.4$nearest.base=="Duluth IAP ANG"|USAF.4$nearest.base=="Fresno Yosemite I
AP"|USAF.4$nearest.base=="Horsham ANG"|USAF.4$nearest.base=="Hulman RAP ANG"|
USAF.4$nearest.base=="Jackson-Evers IAP ANG"|
USAF.4$nearest.base=="Joint Base Charleston"|
USAF.4$nearest.base=="Kulis ANG (Ted Stevens IAP)"|
USAF.4$nearest.base=="Louisville IAP (Standiford Field) ANG"|
USAF.4$nearest.base=="Martin State Airport ANG"|USAF.4$nearest.base=="MCB Haw
aii"|USAF.4$nearest.base=="McClellan AFB"|
USAF.4$nearest.base=="Moffett Field ANG"|
USAF.4$nearest.base=="NAS Pensacola  (Multi-Sites)"|
USAF.4$nearest.base=="New Castle Airport ANG"|
USAF.4$nearest.base=="Peterson AFB"|
USAF.4$nearest.base=="Quonset State Airport (ANG)"|
USAF.4$nearest.base=="Rickenbacker ANGB"|
USAF.4$nearest.base=="Toledo Express Airport ANG"|
USAF.4$nearest.base=="Tulsa IAP ANG"|USAF.4$nearest.base=="W K Kellogg Airpor
t"|USAF.4$nearest.base=="Yeager Airport ANG" )

USAF.6 <-USAF.4[remove4,]

# Step 13. Combine the two dataframes.

USAF.7<-rbind(USAF.6,USAF.5)
USAF.9<-USAF.7

# Step 15. Remove species guilds and groups. Left with 33,000 records.

remove.other<-which(USAF.9$Species..common.name.=="Perching Birds"|
        USAF.9$Species..common.name.=="No Feather Remains Found"|
          USAF.9$Species..common.name.=="No Wildlife Received"|
          USAF.9$Species..common.name.=="Swallows and Martins"|
   USAF.9$Species..common.name.=="American Wood-Warblers and Conebills"|
        USAF.9$Species..common.name.=="Plovers, Lapwings, and Dotterels"|
        USAF.9$Species..common.name.=="Thrushes and Forktails"|
        USAF.9$Species..common.name.=="Pigeons and Doves"|
        USAF.9$Species..common.name.=="Sparrows, Buntings, Finches"|
        USAF.9$Species..common.name.=="American Warblers"|
        USAF.9$Species..common.name.=="white-headed gull complex"|
        USAF.9$Species..common.name.=="Canaries, Seedeaters, Serins"|
        USAF.9$Species..common.name.=="Ducks, Geese, and Swans"|
  USAF.9$Species..common.name.=="American Orioles, Caciques, Blackbirds"|
USAF.9$Species..common.name.=="Nighthawks, Nightjars, Poor-wills, etc."|
USAF.9$Species..common.name.=="Sandpipers, Snipes, Stints, etc."|
USAF.9$Species..common.name.=="Shorebirds"|
USAF.9$Species..common.name.=="Gulls and Kittiwakes"|
USAF.9$Species..common.name.=="Hawks, Eagles, Kites, etc."|
USAF.9$Species..common.name.=="New World Flycatchers."|
USAF.9$Species..common.name.=="Gulls, Kittiwakes, and Terns"|
```

```
USAF.9$Species..common.name.=="Hawks, Eagles, Vultures, Falcons, etc."|
USAF.9$Species..common.name.=="Golden-crowned/White-crowned
Sparrow complex"|
           USAF.9$Species..common.name.=="Cuckoos, Roadrunners, Coucals"|
           USAF.9$Species..common.name.=="Dabbling Ducks"|
           USAF.9$Species..common.name.=="Hummingbirds"|
             USAF.9$Species..common.name.=="Rodents (Mammals)"|
USAF.9$Species..common.name.=="Alder/Willow Flycatcher complex"|
             USAF.9$Species..common.name.=="Bats (Mammals)"|
             USAF.9$Species..common.name.=="BAT"|
   USAF.9$Species..common.name.=="Vesper Bats"|
 USAF.9$Species..common.name.=="Blue-winged Teal/Cinnamon Teal complex"|
USAF.9$Species..common.name.=="Crows, Jays, and Magpies"|
USAF.9$Species..common.name.=="Hermit/Townsend's Warbler complex"|
  USAF.9$Species..common.name.=="Herons, Bitterns, Egrets"|
  USAF.9$Species..common.name.=="Herons and Egrets"|
  USAF.9$Species..common.name.=="Jacamars, Puffbirds, Toucan, Woodpeckers, et
c."|
    USAF.9$Species..common.name.=="Kingbirds, Flycatchers, and Attilas"|
  USAF.9$Species..common.name.=="Mallard/American Black Duck complex"|
   USAF.9$Species..common.name.=="New World Vultures and Condors"|
  USAF.9$Species..common.name.=="Nightjars, Frogmouths, Potoos, etc."|
  USAF.9$Species..common.name.=="Orioles, Blackbirds, Oropendolas"|
   USAF.9$Species..common.name.=="Owls, Barn-Owls, Screech-Owls, Scops-Owls,
etc."|
   USAF.9$Species..common.name.=="Owls, Screech-Owls, Scop-Owls, etc."|
   USAF.9$Species..common.name.=="Pigeons, Doves, and Sandgrouses"|
     USAF.9$Species..common.name.=="Pigeons, Doves, etc."|
  USAF.9$Species..common.name.=="Quails, Pheasants, Partridges, etc."|
   USAF.9$Species..common.name.=="Rabbits, Hares, and Pikas (Mammals)"|
     USAF.9$Species..common.name.=="Raccoons and relatives"|
     USAF.9$Species..common.name.=="Rails, Crakes, Coots, Gallinules"|
    USAF.9$Species..common.name.=="Siskins, Rosefinches, Canaries"|
   USAF.9$Species..common.name.=="Swifts, Swiftlets, Needletails, etc."|
   USAF.9$Species..common.name.=="Tanagers, Euphonias, Honeycreepers"|
   USAF.9$Species..common.name.=="Thrushes, Robins, Wheatears, Redstarts"|
     USAF.9$Species..common.name.=="Turtles, Tortoises, and Terrapins"|
    USAF.9$Species..common.name.=="undetermined bird"|
     USAF.9$Species..common.name.=="Wrynecks, Woodpeckers, Piculets, Flickers
, etc."|
 USAF.9$Species..common.name.=="Aechmophorus grebe"|
 USAF.9$Species..common.name.=="American Cuckoos"|
  USAF.9$Species..common.name.=="American Opossums"|
  USAF.9$Species..common.name.=="Amphibians"|
  USAF.9$Species..common.name.=="Barn-Owls"|
  USAF.9$Species..common.name.=="Barn-Owls"|
   USAF.9$Species..common.name.=="Calidris sandpiper"|
  USAF.9$Species..common.name.=="Calidris sandpiper"|
  USAF.9$Species..common.name.=="Catharus Thrush"|
    USAF.9$Species..common.name.=="Cats"|
```

```
  USAF.9$Species..common.name.=="Chaffinches, Bramblings"|
  USAF.9$Species..common.name.=="Hybrid Gull"|
  USAF.9$Species..common.name.=="Common/Hoary Redpoll complex"|
   USAF.9$Species..common.name.=="dabbling duck"|
   USAF.9$Species..common.name.=="Deer"|
  USAF.9$Species..common.name.=="Diving Ducks"|
  USAF.9$Species..common.name.=="Falcons"|
   USAF.9$Species..common.name.=="Frogs and Toads"|
  USAF.9$Species..common.name.=="Frogs, Turtles, Snakes"|
  USAF.9$Species..common.name.=="Golden-crowned/White-crowned Sparrow complex
"|
  USAF.9$Species..common.name.=="Grebes"|
    USAF.9$Species..common.name.=="Hares and Rabbits"|
  USAF.9$Species..common.name.=="Larks"|
  USAF.9$Species..common.name.=="Meadowlark species"|
   USAF.9$Species..common.name.=="Mouse-eared Bats"|
   USAF.9$Species..common.name.=="New World Flycatchers"|
  USAF.9$Species..common.name.=="Nighthawks"|
  USAF.9$Species..common.name.=="No Data"|
  USAF.9$Species..common.name.=="Old World pipistrelle bat"|
  USAF.9$Species..common.name.=="Other"|
  USAF.9$Species..common.name.=="Plovers and Dotterels"|
  USAF.9$Species..common.name.=="Reptiles"|
  USAF.9$Species..common.name.=="Sparrows and Weavers"|
  USAF.9$Species..common.name.=="Squirrels"|
  USAF.9$Species..common.name.=="Swifts, Swiftlets, etc."|
  USAF.9$Species..common.name.=="Turacos and Cuckoos"|
   USAF.9$Species..common.name.=="Vireos"|
  USAF.9$Species..common.name.=="Wagtails, Pipits"|
  USAF.9$Species..common.name.=="Woodcocks"|
  USAF.9$Species..common.name.=="Wrens"|
USAF.9$Species..common.name.=="Free-tailed Bats"|
USAF.9$Species..common.name.=="Hairy-tailed Bats"|
USAF.9$Species..common.name.=="Empidonax Flycatcher"|
USAF.9$Species..common.name.=="Opossum"|
USAF.9$Species..common.name.=="Wood Warbler"|
USAF.9$Species..common.name.=="Chaffinches, Bramblings"|
USAF.9$Species..common.name.=="Hybrid Gull"|
USAF.9$Species..common.name.=="Aythya diving duck")
USAF.10 <-USAF.9[-remove.other,]
nrow(USAF.10)

## [1] 40865

speciesNames<-read.csv("Species.names.2.csv",header=T)
combined<-data.frame(USAF.10,
            Species..common.name.<-data.frame
     (speciesNames=speciesNames$new.name
     [match(USAF.10$Species..common.name.,speciesNames$old.name)]))
```

```r
consolidateNames<-read.csv("Consolidate.3.csv",header=T)
df.1<-data.frame(combined,
            speciesNames<-data.frame
      (cNames=consolidateNames$new.name
      [match(combined$speciesNames,consolidateNames$old.name)]))

birdmass<-read.csv("BirdMass.csv",header=T)
hazard.df.mass<-data.frame(df.1,
            mass<-data.frame(mass=birdmass$BMASS
                [match(df.1$cNames,
                        birdmass$BNAME)]))

USAF.EOF<-read.csv("EOF USAF.csv")
USAF.11.EOF<-data.frame(USAF.10,
            EOF<-data.frame(EOF=USAF.EOF$Wildlife.Strike.Affect.on.Flight
[pmatch(USAF.10$Event.Report.Number,USAF.EOF$Mishap.ID)]))

z <- hazard.df.mass[order(hazard.df.mass$Event.Report.Number, hazard.df.mass$
mass, decreasing=TRUE),]
write.csv(z,"check.order.csv")
USAF.11<-as.data.frame(z[!duplicated(z$Event.Report.Number), ])
write.csv(USAF.11,"check.order.2.csv")

# Step 16. Compare column names of Navy and USAF datasets.

names(df.9)
```

```
##  [1] "X.1"               "X"                 "RPRTBL_EVENT_SERL"
##  [4] "HT_ID"             "EVENT_DATE"        "EVENT_SEVTY_C"
##  [7] "RPRTG_UIC"         "ACFT_MODEL"        "BUNO_FAA_IDN"
## [10] "ACFT_DMG_COST"     "SPECIES_SERL"      "SPECIES_C"
## [13] "SPECIES"           "SPECIES_GRP_C"     "SPECIES_GRP"
## [16] "SPECIES_TYP_C"     "SPECIES_TYP"       "DMG_CMTS"
## [19] "EVENT_NARR"        "INVLVD_FAC_NARR"   "EVENT_TIME"
## [22] "ALT_AGL"           "ID"                "true.ID"
## [25] "country"           "state"             "state.1"
## [28] "time"
```

```r
nrow(df.9)
```

```
## [1] 4433
```

```r
nrow(USAF.11)
```

```
## [1] 36767
```

```r
df.9$Branch<- "USN"
names(USAF.11)
```

```
##  [1] "Event.Report.Number"          "Event.Date..Local"
##  [3] "Event.Class.Flagword"         "Event.Time..Local"
##  [5] "Total.Event.Cost.with.Injuries" "Nearest.Base"
```

```
##  [7] "Nearest.Airfield"                "U.S..State"
##  [9] "Altitude"                        "General.MDS.Grouping"
## [11] "Order..common.name."             "Species..common.name."
## [13] "Impact.Point"                    "speciesNames"
## [15] "cNames"                          "mass"

USAF.11$Branch<- "USAF"
costs<-subset(USAF.11,Total.Event.Cost.with.Injuries>0)
a<-sum(USAF.11$Total.Event.Cost.with.Injuries)
a

## [1] 418283088

a/23

## [1] 18186221

# Step 17. Subset dataframes to have equal columns.

df.9 = subset(df.9, select = c(RPRTBL_EVENT_SERL,
      EVENT_DATE,ACFT_DMG_COST,EVENT_SEVTY_C,ACFT_MODEL,RPRTG_UIC,ALT_AGL,SPE
CIES_GRP,true.ID,state,time,Branch))
USAF.12= subset(USAF.11,select=c(Event.Report.Number,Event.Date..Local,
    Event.Class.Flagword,Event.Time..Local,Total.Event.Cost.with.Injuries,Nea
rest.Base,Altitude,General.MDS.Grouping,Species..common.name.,Order..common.n
ame.,U.S..State,Branch))

# Step 18. Rename columns to match.

colnames(df.9)[colnames(df.9)=="RPRTBL_EVENT_SERL"] <- "Event.Report.Number"
colnames(df.9)[colnames(df.9)=="EVENT_DATE"] <- "Event.Date..Local"
colnames(df.9)[colnames(df.9)=="EVENT_SEVTY_C"] <- "Event.Class.Flagword"
colnames(df.9)[colnames(df.9)=="RPRTG_UIC"] <- "Nearest.Base"
colnames(df.9)[colnames(df.9)=="SPECIES_GRP"] <- "Order..common.name."
colnames(df.9)[colnames(df.9)=="ALT_AGL"] <- "Altitude"
colnames(df.9)[colnames(df.9)=="state"] <- "U.S..State"
colnames(df.9)[colnames(df.9)=="true.ID"] <- "Species..common.name."
colnames(df.9)[colnames(df.9)=="time"] <- "Event.Time..Local"
colnames(df.9)[colnames(df.9)=="ACFT_MODEL"] <- "General.MDS.Grouping"
colnames(df.9)[colnames(df.9)=="ACFT_DMG_COST"] <- "Total.Event.Cost.with.Inj
uries"

combined<-rbind(df.9,USAF.12)

airframe<-read.csv("airframe.MBP.csv",header=T)
combined$airframe<-"NA"
data.airframe<-data.frame(combined,
            airframe<-data.frame
      (airframe=airframe$Airframe.grouped
      [match(combined$General.MDS.Grouping,airframe$Airframe.raw)]))
aircraft<-as.data.frame(table(combined$General.MDS.Grouping))
table(data.airframe$airframe.1)
```

```
##
##         fighter              heavy heavy/rotorcraft               Other
##           10781              22738             225                 674
##  propeller/heavy  propeller/small        rotorcraft            stealth
##             247                884            1227                1095

rotorcraft<-which(data.airframe$airframe.1=="heavy/rotorcraft"|data.airframe$
airframe.1=="rotorcraft")
combined<-data.airframe[-rotorcraft,]
table(combined$airframe.1)

##
##         fighter              heavy heavy/rotorcraft               Other
##           10781              22738               0                 674
##  propeller/heavy  propeller/small        rotorcraft            stealth
##             247                884               0                1095

save(combined,file="combined.Rdata")
write.csv(combined,"combined.csv")

# Step 19. Merge databases.

save(df.9,file = "Navy.Rdata")
save(USAF.12,file = "USAF.Rdata")
save(USAF.11.EOF,file="USAF.EOF.Rdata")
write.csv(USAF.12,"USAF.csv")
write.csv(df.9,"Navy.csv")
write.csv(USAF.11.EOF,file="USAF.EOF.csv")
nrow(combined)

## [1] 39748

nrow(USAF.12)

## [1] 36767

nrow(df.9)

## [1] 4433

# Step 20. Break up by airframe.
fighter<-which(combined$airframe.1=="fighter")
fighter<-data.airframe[fighter,]
save(fighter,file = "fighter.Rdata")

heavy<-which(combined$airframe.1=="heavy")
heavy <-data.airframe[heavy,]
save(heavy,file = "heavy.Rdata")

stealth<-which(combined$airframe.1=="stealth")
stealth <-data.airframe[stealth,]
save(stealth,file = "stealth.Rdata")
```

1.2 Consolidate

```r
# Strike data processing

# Preamble - Load libraries and clear environments
library(knitr)
remove(list=ls())

#Step 1. Consolidate names.

load("combined.Rdata")
speciesNames<-read.csv("Species.names.2.csv",header=T)
combined<-data.frame(combined,
            Species..common.name.<-data.frame
      (speciesNames=speciesNames$new.name
      [match(combined$Species..common.name.,speciesNames$old.name)]))
species<-as.data.frame(table(combined$speciesNames))
d<-subset(species,Freq>=20)
write.csv(d,"check.number.csv")
consolidateNames<-read.csv("Consolidate.3.csv",header=T)
df.1<-data.frame(combined,
            speciesNames<-data.frame
      (cNames=consolidateNames$new.name
      [match(combined$speciesNames,consolidateNames$old.name)]))
species<-as.data.frame(table(df.1$cNames))
write.csv(df.1,"PLOS.ONE.data.csv")

#Step 2. Number of strikes over 20.

species.6<-as.data.frame(table(df.1$cNames))
df.2<-subset(species.6,Freq>=20)
colnames(df.2)[colnames(df.2)=="Freq"] <- "Reports.noting.status.of.damage"
colnames(df.2)[colnames(df.2)=="Var1"] <- "SPECIES"

#Step 3. Number of strikes non-damaging strikes.

unique(df.1$Event.Class.Flagword)

## [1] C        D        B        No Data <NA>     H        E        A
## Levels: A B C D H No Data E

table(df.1$Event.Class.Flagword)

##
##        A       B       C       D       H No Data       E
##       26     104     875     202     336   33932    2753

remove4<-which(df.1$Event.Class.Flagword=="No Data")
```

```r
df.3 <-df.1[-remove4,]
costs<-subset(df.3,Total.Event.Cost.with.Injuries>0)
median(costs$Total.Event.Cost.with.Injuries)

## [1] 7952

species.7<-as.data.frame(table(df.3$cNames))

df.4<-species.7
colnames(df.4)[colnames(df.4)=="Freq"] <- "Number.with.damage"
colnames(df.4)[colnames(df.4)=="Var1"] <- "SPECIES"

35066+2810

## [1] 37876
```

#Step 4. Number of strikes with major damage.

```r
remove5<-which(df.1$Event.Class.Flagword=="No Data"|
               df.1$Event.Class.Flagword=="H"|
               df.1$Event.Class.Flagword=="D"|
               df.1$Event.Class.Flagword=="E")

df.7 <-df.1[-remove5,]
costs<-subset(df.7,Total.Event.Cost.with.Injuries>0)
median(costs$Total.Event.Cost.with.Injuries)

## [1] 72864.5

species.8<-as.data.frame(table(df.7$cNames))
df.9<-species.8
colnames(df.9)[colnames(df.9)=="Freq"] <- "Number.with.maj.damage"
colnames(df.9)[colnames(df.9)=="Var1"] <- "SPECIES"
df.10<-merge(df.9,df.4, "SPECIES")
```

#Step 5. Save.

```r
df.11<-merge(df.10,df.2,"SPECIES")
df.11$non.damaging<-(df.11$Reports.noting.status.of.damage-df.11$Number.with.
damage)
save(df.11,file = "Hazard.ranking.groups.Rdata")
write.csv(df.11,"Hazard.score.groups.csv")
```

1.3 Hazard rank

```r
#Step 1. Load what was created in the filtering process.

load("Hazard.ranking.groups.Rdata")
attach(df.11)
birdmass<-read.csv("BirdMass.csv",header=T)
df.11<-data.frame(df.11,
                  mass<-data.frame(mass=birdmass$BMASS
                    [match(df.11$SPECIES,
                           birdmass$BNAME)]))

#Step 2. Calculate the damage rank.

df.11$Percent.with.damage <-
  ((Number.with.damage/Reports.noting.status.of.damage)*100)

df.11$Damage.rank<-rank(-df.11$Percent.with.damage,ties.method = "min")

#Step 3. Calculate the major damage rank.

df.11$Percent.with.maj.damage <-
  ((Number.with.maj.damage/Reports.noting.status.of.damage)*100)

df.11$Maj.Damage.Rank <-
  rank(-df.11$Percent.with.maj.damage,ties.method = "min")

#Step 4. Calculate the sum of ranks and percentages.

df.11$Sum.of.Ranks <- apply(df.11[,c("Damage.rank","Maj.Damage.Rank")], 1, su
m)

df.11$Sum.of.percentages <-
  apply(df.11[,c("Percent.with.damage","Percent.with.maj.damage")], 1, sum)

x<-max(df.11$Sum.of.percentages)

df.11$Relative.hazard.score <- round(((df.11$Sum.of.percentages/x)*100))

df.11$Composite.rank <- rank(df.11$Sum.of.Ranks,ties.method = "min")
df.11$non.damaging<-(df.11$Reports.noting.status.of.damage-df.11$Number.with.
damage)
write.csv(df.11,"Final.hazard.combined.csv")

#Step 5. Remove mammals.

mammals<-which(df.11$SPECIES=="White-tailed Deer"|
               df.11$SPECIES=="Coyote"|
```

```
                df.11$SPECIES=="Bats")
df.9<-df.11[-mammals,]

#Step 6. Calculate the damage rank.

df.9$Percent.with.damage <-
  ((df.9$Number.with.damage/df.9$Reports.noting.status.of.damage)*100)

df.9$Damage.rank<-rank(-df.9$Percent.with.damage,ties.method = "min")

#Step 7. Calculate the major damage rank.

df.9$Percent.with.maj.damage <-
  ((df.9$Number.with.maj.damage/df.9$Reports.noting.status.of.damage)*100)

df.9$Maj.Damage.Rank <-
  rank(-df.9$Percent.with.maj.damage,ties.method = "min")

#Step 8. Calculate the sum of ranks and percentages.
df.9$Sum.of.Ranks <- apply(df.9[,c("Damage.rank","Maj.Damage.Rank")], 1, sum)

df.9$Sum.of.percentages <-
  apply(df.9[,c("Percent.with.damage","Percent.with.maj.damage")], 1, sum)

x<-max(df.9$Sum.of.percentages)

df.9$Relative.hazard.score <- round(((df.9$Sum.of.percentages/x)*100))

df.9$Composite.rank <- rank(df.9$Sum.of.Ranks,ties.method = "min")
df.9$non.damaging<-(df.9$Reports.noting.status.of.damage-df.9$Number.with.dam
age)
write.csv(df.9,"Final.hazard.birds.csv")
```