USING POWER ANALYSIS TO DETERMINE SURVEY METHODOLOGY: A CASE STUDY WITH HARLEQUIN DUCKS

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SUMMARY
Variation in the numbers of animals counted may be natural (e.g., births, deaths, weather effects) or due to the flaws of the chosen monitoring technique (e.g., observer differences, different fractions of individuals being counted each time, survey length, number of plots). This variation in numbers partially obscures the presence of any long-term trends. The probability that a monitoring program will detect a trend in sample counts when the trend is real, despite the variations in the count data, represents its statistical "power." The consequences of ignoring statistical power include collection of count data that are insufficient to make reliable inferences about population trends, or conversely, the collection of data in excess of what is needed. When the objective is to monitor a population trend from an index of population abundance over time, we need to know what the probability is that a significant change in population size can be detected from the surveys.

MONITOR is a free program available from the United States Geological Survey web site at < http://www.mp1-pwrc.usgs.gov/powcase/monitor.html >. The power estimate generated by MONITOR indicates how effective a monitoring program is at detecting population trends. Three survey variables are easily changed in the program: the time period over which you wish to detect a trend, the number of surveys that are conducted each year, and the variances (S.D.). I present power analyses of roadside, boating and helicopter surveys for Harlequin Ducks (*Histrionicus histrionicus*) in the Rocky Mountains of Alberta that allowed me to make recommendations on survey methodology for two monitoring plans.

1. POWER ANALYSIS AND DETECTING TRENDS

Inherent in any monitoring program is variation in the numbers of animals counted. The variation may be natural or real (e.g., births, deaths, weather effects) or it may be an artefact due to the flaws of the chosen monitoring technique (e.g., observer differences, different fractions of individuals being counted each time, survey length, number of plots). This variation in numbers partially obscures the presence of any long-term trends. The probability that a monitoring program will detect a trend in sample counts when the trend is occurring, despite the variations in the count data, represents its statistical "power." The consequences of ignoring statistical power include collection of count data that are insufficient to make reliable inferences about population trends, or conversely, the collection of data in excess of what is needed (1). Small sample sizes, with high variability, will reduce our ability to detect change (power).

1.1 Type I and Type II errors

When the objective is to monitor a population trend from an index of population abundance over time, we must test the null hypothesis that there has not been a change in population index between two time points against the alternative that the population *has* changed. If a significant change in population size has occurred, we want to know what the probability is that it has been detected from our surveys.

There are at least two types of errors that can be made every time a decision is made about whether or not to reject a null hypothesis of no change (Table 1). A Type I error (also referred to as α-error) is made when a true null hypothesis is rejected; concluding that a significant change in population has occurred, when in fact it has not. The rate at which Type I errors are accepted

(α) is set by the researcher. The probability of accepting the null hypothesis when it is *not* true, concluding that no change has occurred when in fact it has, is known as a Type II error (β-error).

Thus, power is really the likelihood of *correctly* rejecting the null hypothesis, and is defined as $1 - \beta$. As a probability, power is expressed as a number between 0 (low power) and 1 (high power), although sometimes it is expressed as a percentage.

Table 1. Decisions and results of testing the null hypothesis. Probabilities associated with each decision are given in parentheses. Adapted from Steidl et al. (2).

	Decision and result	
Reality	Accept null hypothesis	Reject null hypothesis
Null hypothesis is true	Correct ($1 - \alpha$)	Type I error (α)
Null hypothesis is false	Type II error (β)	Correct ($1 - \beta$)

1.2 Significance level

The significance level, or α-level, is the percentage of time a researcher is willing to incorrectly conclude that a population has undergone significant change when it actually has not – in effect, "cry wolf." There is a direct trade-off between significance level and the power of a study to detect population changes that are occurring. Although an $\alpha = 0.05$ is common in most experimental settings, many conservationists feel that an α-level of 0.10-0.20 is better suited to monitoring for conservation management, as the consequences for the species of sounding a false alarm are small when compared to the consequences of failing to detect a population decline and not taking conservation action, because the standards are set too high (with a low α) (1, 3).

Although a common criterion for power is 0.80 – a monitoring program with power estimates exceeding 0.80 would detect trends, should they occur, > 80% of the time (4) – some researchers suggest using β-values of 0.90 as the minimum acceptable probability to detect trends (1, 3). This balances statistical, logistical and budgetary constraints. If the β-values obtained in simulations are consistently higher then a lower α-level could be used.

A good starting point for a power analysis is $\alpha = \beta = 0.10$, or a 10% probability of incorrectly concluding there was a significant population change and a 10% probability of not detecting a significant trend.

1.3 Power analysis program MONITOR

There are many software programs available to help in power analysis (see the review in Thomas and Krebs (5), although such reviews are quickly outdated). MONITOR (1) is a free program available from the United States Geological Survey monitoring website at <http://www.mp1-pwrc.usgs.gov/powcase/index.html>. This software estimates the statistical power of population monitoring programs relative to 13 different attributes, ranging from the number of plots monitored to the significance level associated with trend detection (Table 2 (6)).

2. CASE STUDY OF MONITORING POPULATION TRENDS IN HARLEQUIN DUCKS

Harlequin Ducks (*Histrionicus histrionicus*) are small, colourful sea ducks that spend most of the year at coastal areas, migrating inland only long enough to breed along mountain streams (the only duck to do so in North America). As with other sea ducks they tend to have a long lifespan, low productivity, and delayed breeding (19). Within North America, the species occurs along both the Atlantic and Pacific coasts.

In 1990, the Harlequin Duck was listed as "Endangered" in eastern Canada, becoming the first North American duck to reach such critical status in modern times (7); it was downlisted to

“Special Concern” in 2002 (8). The Pacific population, historically larger than the Atlantic population, is also showing signs of decline (9), based on estimates of adult survival on the wintering area (10) and low recruitment rates (11, 12). In Alberta, Harlequin Ducks are considered “Sensitive” (13). In British Columbia Harlequin Ducks are considered a species at risk with a S4/YCMG ranking (14).

Concern over population trends of Harlequin Ducks in the Canadian Rockies started in Jasper National Park in 1992 (15) and resulted in a study on the Maligne River (16), where there were potential impacts from increased white-water rafting. In Banff National Park (BNP), concern arose over the potential impacts of twinning the Trans Canada Highway along the Bow River (17).

Table 2. Attributes of a monitoring program that can be manipulated in the MONITOR software (adapted from Gibbs (6)).

Attributes
Number of plots monitored
Number of counts conducted on each plot during each survey occasion
Magnitude of counts on each plot
Variation in counts on each plot
Plot weighting schemes
Number of surveys conducted (days, months, years)
Occasions of those surveys in time (e.g., annual vs. biennial)
Nature of trends ongoing in the population monitored (linear vs. exponential)
Variation in trends among plots (if more than one plot is surveyed)
Significance level used for trend detection
Number of tails considered in statistical tests of trend significance
Whole versus fractional counts
Constants used in data transformations

2.1 Population trend

One of the first questions to be answered during a power analysis is “What magnitude of population change needs to be detected?” This is frequently given in terms of percent change over a given time period, and all things being equal, more samples will be required to detect smaller trends over shorter time intervals.

The quantitative criterion used by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for a “threatened” species is a population size reduction of ≥ 30% that is “observed, estimated, inferred or suspected over the last 10 years or 3 generations, whichever is longer” (18). Three generations for Harlequin Ducks could vary from 9-15 years, as females do not usually breed until they are three years of age, or older (9). Using the converter sub-program in MONITOR, a 30% decline over 10 years would be a decline of 3.5% per year (Table 3). Goudie et al. (19) suggest that a decrease in an adult Harlequin Duck population of 2-3% per year is enough to cause the population to decline. For the purposes of this power analysis, I wanted to detect a 3% annual decline (MONITOR does not process fractional changes), but show outputs from -10% to +10% changes in population size.

2.2 Roadside surveys on the Bow River

The Bow River, between Lake Louise and Banff, supports about 150 adult Harlequin Ducks (17), which is the highest known density on a breeding stream in North America (9). While the adult population on the Bow River appeared to be stable, a long-term plan was needed to monitor population trends, survival rates and productivity (20). Here I will only discuss the analysis undertaken to determine the appropriate surveys needed to track population trends.

During the Bow River study, roadside surveys were conducted to obtain numbers of banded and unbanded birds, to estimate the population size using a Capture-Mark-Recapture/Resighting (CMR) methodology (17). The number of surveys varied between 7 and 12 per year (Table 4). The question was: how many surveys would be necessary to determine if there was a significant change in the population size over some period of time? Aside from the necessity to obtain accurate trend information to guide management, this information would also be important to make efficient use of time and resources for surveys.

Table 3. Comparison of short-term annual trends (-3%, -5%, -7%, -10%) vs. the long-term trend over 5-, 10- and 20-year sampling intervals. Figures calculated using the converter sub-program in MONITOR (1).

	-3%	-5%	-7%	-10%
Trend over 5 years	-14.13	-22.62	-30.43	-40.95
Trend over 10 years	-26.26	-40.13	-51.60	-65.13
Trend over 20 years	-45.62	-64.15	-76.58	-87.84

Table 4. Population size data for Harlequin Ducks on the Bow River in Banff National Park, during roadside surveys (*n*), 1995-99 (17).

Year	Pop. Est. (*N*)	Variance (S^2)	S.D.	S.E.	95% C.I.
1995 (*n*=7)	111	186	14	1.4	27
1996 (*n*=12)	150	617	25	2.0	49
1997 (*n*=10)	152	532	23	1.9	45
1998 (*n*=10)	157	1264	36	2.9	70
1999 (*n*=11)	154	718	27	2.3	52.5
Pooled median	152	617	25	2	49

Table 5 outlines the default values (based on the data from Table 4) that were used for the MONITOR simulations. Simulations were run after altering the following variables: number of surveys per year, number of years of surveys, and the α-level. The one variable that could not be altered is the number of plots, as there is only one possible route for Harlequin Ducks along the Bow River in BNP.

Columns A, B and C in Table 6 show the effect on power of significance levels of 0.05, 0.10 and 0.20, but using the default values none of these combinations produce the desired power of 0.90. Columns D through F set the time frame over 10 years (which would fit the COSEWIC criteria for a threatened population), but varying the number of surveys per year, and whether they are done annually or biennially. If seven surveys were conducted each year for 10 years (70 surveys total), there would be an 88% probability (which is very close to the desired 90%) of detecting an annual 3% decline (column E), or a 30% decline in total. If biennial surveys were conducted (every two years), it would require eight surveys (40 surveys total) during the same time period to detect the same trend, with a power of 91%. Thus, it may be more cost effective (40 surveys vs. 70 surveys total) to conduct the surveys every other year.

Column F shows that if the standard deviation were reduced to 20.0 from 25.55 then it would require only five surveys biennially to obtain a power of 90%. Variance might be lowered by 1) having more marked birds in the population, 2) determining whether birds are marked or not 100% of the time, 3) covering more of the river on each survey, and 4) shortening the time frame of the surveys from six weeks to 3-4 weeks.

If we are willing to be wrong more often, and set the α = 0.20 and power = 0.80, then three surveys annually (30 surveys total) or five surveys biennially (25 surveys total) would detect a 30% decline over the 10 years. Of course, if we are willing to wait for a 50% decline (-7% annually), then we could work with that also.

Table 5. Default and test values used in MONITOR (1) simulations of roadside surveys for Harlequin Ducks on the Bow River in Banff National Park.

Variable	Default Value(s)	Test Values
Number of plots monitored	1	N/A – there is only one survey route
Counts/plot/survey	10 surveys per year	3, 5, 6, 7, 8, 9, 10, 13
Initial values	Mean = 153, S.D. = 25 (C.V. = 16%), Weight = 1	S.D. = 20 and 25
Number of years	5	3 to 10
Survey occasions	Yearly	Yearly and biennially
Trend type	Exponential – models population change better than linear	N/A
Significance level	α = 0.05	α = 0.05, 0.10, 0.20
Number of tails	Two-tailed test	N/A
Constant added	0.01	N/A
Trend CV	0 – trend CV does not apply in single plot surveys	N/A
Rounding	Whole numbers	N/A
Trend coverage	Partial	-10% to +10% per year
Replications	1000	N/A

Table 6. Power analysis simulations of roadside surveys for Harlequin Ducks on the Bow River in Banff National Park. Default values as in Table 5. Variables altered are: number of surveys per year, number of years of surveys, α-level and standard deviation. Power estimates in bold face indicate the first estimate greater than or equal to 0.90 for that combination of variables, except for columns G and H where power ≥ 0.80.

Trend (%)	A	B	C	D	E	F	G	H
Surveys/year	10	10	10	7	8	5*	3	5
# of years	5	5	5	10	10**	10**	10	10**
Total # surveys	50	50	50	70	40	25	30	25
α-level	0.05	0.10	0.20	0.10	0.10	0.10	0.20	0.20
-10	**1.00**	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00
-5	0.81	0.87	**0.92**	1.00	1.00	1.00	1.00	0.99
-3	0.42	0.55	0.70	**0.88**	**0.91**	**0.90**	**0.90**	**0.87**
-2	0.22	0.31	0.50	0.62	0.67	0.65	0.71	0.67
-1	0.09	0.16	0.30	0.26	0.29	0.27	0.37	0.33
No trend	0.05	0.10	0.18	0.11	0.11	0.09	0.22	0.20
+1	0.13	0.17	0.30	0.29	0.32	0.29	0.44	0.35
+2	0.25	0.34	0.50	0.72	0.73	0.74	0.80	0.73
+3	0.46	0.61	0.73	**0.95**	**0.97**	**0.97**	**0.98**	**0.95**
+5	**0.91**	**0.95**	**0.96**	1.00	1.00	1.00	1.00	1.00
+10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*** S.D. = 20 ** biennial surveys (5 surveys every other year for 10 years)**

2.3 Boating surveys on the Bow River

During the Bow River study, boating surveys were done a number of times each year to describe abundance of Harlequin Ducks, their distribution on the river, and their productivity (17). Over the five years, there was an average of three surveys done per year from early May to mid-June. The mean number of birds observed was 58.27 and the standard deviation was 22.29 (unpubl. data). Table 7 shows the results of power analyses for boating surveys. It would take 15 surveys per year for 10 years (150 surveys total; column B) to detect a 30% decline with 90% probability. If the variance could be reduced, then it would only take 10 surveys to the same probability (column C). But if the variance could be reduced and the mean number of ducks counted increased, through using more experienced paddlers and birders, then it would only take 8 surveys to obtain a 91% probability of detecting the decline (column D).

Again, if we are willing to be wrong more often, and set the $\alpha = 0.20$ and power = 0.80, then eight surveys annually (80 surveys total) would detect a 30% decline over the 10 years (column E), with the original mean and standard deviation. If both the mean could be increased and the standard deviation decreased, then four surveys annually for 10 years (40 surveys total; column F).

Table 7. Power analysis simulations of boating surveys for Harlequin Ducks on the Bow River in Banff National Park. Default values as in Table 5, except initial values were mean = 58.27, S.D. = 22.29. Variables altered are: number of surveys per year, number of years of surveys, α-level, mean, and S.D. Power estimates in bold face indicate the first estimate greater than or equal to 0.90 for that combination of variables, except for columns E and F where power ≥ 0.80.

Trend (%)	A	B	C	D	E	F
Surveys/year	3	15	10*	8**	8	4**
# of years	5	10	10	10	10	10
Total # surveys	15	150	100	80	80	40
α-level	0.10	0.10	0.10	0.01	0.20	0.20
-10	0.41	1.00	1.00	1.00	1.00	1.00
-5	0.19	1.00	1.00	1.00	0.99	0.97
-3	0.13	**0.90**	**0.90**	**0.91**	**0.82**	**0.81**
-2	0.13	0.63	0.61	0.68	0.61	0.58
-1	0.12	0.25	0.30	0.31	0.34	0.36
No trend	0.09	0.09	0.10	0.09	0.21	0.17
+1	0.11	0.30	0.29	0.30	0.35	0.31
+2	0.12	0.73	0.76	0.78	0.68	0.66
+3	0.12	**0.97**	**0.97**	**0.98**	**0.91**	**0.91**
+5	0.21	1.00	1.00	1.00	1.00	1.00
+10	0.53	1.00	1.00	1.00	1.00	1.00

- S.D. = 17 ** Mean = 70, S.D. = 17

2.4 Helicopter surveys on the McLeod River

While writing a long-term plan designed to assess streams for breeding status and to monitor population trends and productivity of Harlequin Ducks in the Bow Region of Alberta, a power analysis was done of using helicopter surveys to count birds (21). As aerial surveys to count Harlequin Ducks had not been conducted in Kananaskis Country, the results of surveys in the McLeod River, Alberta, watershed 1998-2000 (22) were used to analyse the efficacy of the technique.

To estimate visibility of Harlequin Ducks, aerial surveys were conducted on one of the same days as ground surveys, which took 2-3 days (22). When total counts were compared, it was found that visibility from the air was ≥ 70% of the ground counts in 1998 and 2000, and 13-27% in 1999. The low visibility in 1999 was attributed to bright lighting making it difficult to distinguish birds on the shining water. When the total aerial counts were compared to the two-sample population estimates calculated from the ground surveys (22), the results were 51% in 1998 and 25% in 1999 (estimates were unavailable for 2000).

From the work of Kneteman and Hubbs (21), it appeared that aerial surveys have some utility for comparing counts among years but not in calculating a population estimate. To analyse the power of the aerial surveys to detect decreasing or increasing trends the mean count was used from 1998 and 2000 only, as poor light conditions affected the results in 1999.

Table 8 shows that even 10 years of one annual survey would not be sufficient to detect a 30% decline in the population during that time period (column A). But if two surveys were conducted each year, then in 10 years (20 surveys) there would be a 91% probability of detecting a 30% decline (column B). If the standard deviation was able to be reduced to 3.00, then one survey could be done annually or two surveys biennially to obtain sufficient power (columns C and D, respectively). It may be difficult to improve the variance in the aerial surveys, but only conducting surveys during good lighting conditions and utilizing the same experienced observers every time would help.

Again, if we are willing to be wrong more often, and set the $\alpha = 0.20$ and power = 0.80, then two surveys annually (20 surveys total) would detect a 30% decline over the 10 years (column F). One survey annually (column E) and two surveys biennially (column G) don't quite have enough power.

2.5 Options analysis

At this point, the person establishing the monitoring program has a set of questions to answer and decisions to make. The statistical questions are:

- what magnitude of trend do I want to detect?
- over what time frame do I want to detect a change?
- how often am I willing to incorrectly conclude there was a population change?
- how often am I willing to fail to detect a trend?

The answers may vary depending on the species in question, its biology, rarity, threats, the consequences of not detecting a decline, etc. Once these decisions are made, then the choice of appropriate survey frequency can be based on budgetary, personnel and time restraints.

Table 8. Power analysis simulations of helicopter surveys for Harlequin Ducks. Default values as in Table 5, except initial values were mean = 43.5, S.D. = 4.95. Variables altered are: number of surveys per year, number of years of surveys, α-level and standard deviation. Power estimates in bold face indicate the first estimate greater than or equal to 0.90 for that combination of variables, except for columns E to G where power ≥ 0.80.

Trend (%)	A	B	C	D	E	F	G
Surveys/year	1	2	1*	2*	1	2	2
# of years	10	10	10	10**	10	10	10**
Total # of surveys	10	20	10	10	10	20	10
α-level	0.10	0.10	0.10	0.10	0.20	0.20	0.20
-10	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-5	**0.90**	1.00	1.00	1.00	**0.96**	1.00	**0.96**
-3	0.63	**0.91**	**0.93**	**0.94**	0.76	**0.96**	0.76
-2	0.38	0.67	0.72	0.72	0.57	0.78	0.56
-1	0.17	0.29	0.31	0.30	0.33	0.43	0.31
No trend	0.09	0.10	0.11	0.12	0.21	0.21	0.20
+1	0.20	0.29	0.36	0.37	0.33	0.45	0.31
+2	0.50	0.75	0.84	0.81	0.65	**0.87**	0.61
+3	0.81	**0.97**	**1.00**	**0.99**	**0.90**	0.99	**0.89**
+5	**0.99**	1.00	1.00	1.00	1.00	1.00	1.00
+10	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* S.D. = 3 ** biennial surveys (5 surveys every other year for 10 years)

3. CONCLUSIONS

Power analysis can be used for monitoring many species of plants and animals: examples for Himalayan black bears (*Selenarctos thibetanus*), jack-in-the-pulpits (*Arisaema triphyllum*) and call-response surveys for Virginia rails (*Rallus limicola*) are given in Gibbs (6). St. Clair (17) has recently used power analysis to suggest a monitoring strategy for a suite of amphibians in Banff National Park.

Long-term monitoring often suffers due to lack of funding and time restraints. By using a power analysis program such as MONITOR, researchers and program managers can make recommendations regarding monitoring for population change of a species with increased justification and confidence that the chosen methodology will be able to detect a trend. It is important, though, to re-evaluate the analysis as successive years of data become available.

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