

LOST BIRD-YEARS: QUANTIFYING BIRD INJURIES IN NATURAL RESOURCE DAMAGE ASSESSMENTS FOR OIL SPILLS¹

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ABSTRACT

Large oil spills routinely impact hundreds or even thousands of birds. In order to determine the compensation that responsible parties owe the public, trustee agencies typically examine the number of live and dead birds collected to estimate total bird mortality caused by the spill (Ford et al., 1987). In these natural resource damage assessments (NRDA), compensation is typically based upon the potential ecological benefits that flow from a restoration project. In the case of a bird kill, final compensation is based upon the cost of implementing a restoration project and not upon a dollar value per bird.

The dominant paradigm for calculating compensatory restoration for bird injuries is Resource Equivalency Analysis (REA). This paper begins by providing a brief overview of REA when applied to birds. We then examine the REA implications of varying the level of mortality, baseline variability, and demographic variables in a simple population model that tracks both injured and baseline population levels. After finding no evidence that these factors necessarily produce short recovery times, we summarize two general approaches for calculating lost bird-years. We conclude that short recovery times (e.g., one-year) are unlikely for birds when using individual-based measures of injury. Further, we believe that recovery times may be much longer than currently calculated for situations where plausible “recovery mechanisms” cannot be defined.

¹ The ideas presented in this paper are the personal thoughts of the authors and do not reflect the official position of the California Department of Fish and Game.

BIRD RESOURCE EQUIVALENCY ANALYSIS (REA)

REA is an adaptation of Habitat Equivalency Analysis (HEA), but applied to a natural resource (e.g. birds) other than habitat. The basic approach is described by Unsworth and Bishop (1994). Using this methodology, those conducting an NRDA may compare the birds lost over time as a result of a spill to the birds “gained” over time from a compensatory restoration project. The injury is a function of two factors: degree (i.e. the initial number of birds killed) and duration (i.e. the time it takes for the affected population to recover to baseline). Baseline is defined as “the condition of the natural resources and services that would have existed had the incident not occurred” (Oil Pollution Act of 1990 § 990.30). Injuries are often quantified using “bird-years”, the number of birds missing from a population multiplied by the number of years they are absent. At some point, either by natural recovery or direct intervention (often termed “primary restoration”), the impacted population may recover and its trajectory rejoins the baseline population. At that point, no more bird-years are lost. Figure 1 provides a simple illustration.

Lost bird-years may be calculated as:

$$I = \sum_{t=0} (NB_t - N_t)/(1+r)^t \quad (1)$$

where I is the injury in lost bird-years, NB_t and N_t represent the number of birds in the population (at time t) under “baseline” and “injured” scenarios, respectively, t indexes time in years, and r is the annual discount rate.² While there is a tendency to focus on losses due to mortality, differences between baseline (NB_t) and injured (N_t) population trajectories can also result from sub-lethal effects that alter vital rates of surviving individuals (e.g., their survivorship or

² When using REA, future years are typically discounted at 3% per year, consistent with NOAA recommendations for NRDA (National Oceanic and Atmospheric Administration, 1999). This discounting is done based on the assumption that present services are more valuable than future services.

fecundity). The longer it takes for bird populations to return to baseline numbers, the more bird-years are lost and the more restoration is required for compensation. Thus the determination of the recovery path, or the duration of the injury, is central in determining natural resource damages using REA.

Despite the importance of calculating lost bird-years, there is no clear consensus on how to do it. In fact, the quantification has been done using widely varying approaches and based upon a wide array of biological justifications. Examples of oil spill NRDA's that calculated lost bird-years include the *Apex Houston* oil spill of 1986 off California (Swartzman, 1996), the *North Cape* Oil Spill off the coast of Rhode Island in 1996 (Sperduto et al., 1999, 2003), and the *Stuyvesant* oil spill off California in 1999 (California Department of Fish and Game [CDFG] et al., 2004). For the *Anitra* oil spill off New Jersey and the Chalk Point oil spill in Maryland, the unit of measure for injury was adult birds, not bird-years (New Jersey Department of Environmental Protection et al., 2004; National Oceanic and Atmospheric Administration [NOAA] et al., 2002). Other assessments have calculated lost terrapin-years (NOAA et al., 2002) and lost sea turtle-years (NOAA and Florida Department of Environmental Protection, 2002).

These different cases have sometimes calculated lost bird-years as the average age that each individual killed would have lived, sometimes included foregone future generations, and sometimes assumed the impacted population would fully recover after one year. Given the various approaches used to quantify lost bird-years, a detailed investigation of their rationale is warranted.

A SIMPLE MODEL OF POPULATION INJURY

A useful place to start is to examine the assumption of short (e.g., one-year) recovery times from an incident that causes acute mortality of birds. In these situations, fast recovery of bird injures has been justified based on growing populations sizes (Sperduto et al., 1999), demographic rates (e.g. fledging success, survival rates) (Sperduto et al., 1999, 2003; NOAA et al., 2002), low acute mortality (Sperduto et al., 1999; NOAA et al., 2002), and high variability in baseline conditions (Wiens, 1995). In contrast, longer recovery times have been argued because of declining populations (Sperduto et al., 2003), late age of first breeding (Sperduto et al., 1999), low reproductive success (Sperduto et al., 1999, 2003), and large acute mortalities (Sperduto et al., 1999; NOAA et al., 2002). We argue that none of the above factors (by themselves) are sufficient to justify either short or long recovery times when quantifying lost bird-years. The reason is that these factors do not necessarily address the issue of what mechanisms might cause the “baseline” and “injured” trajectories to converge.

We begin by presenting a model to answer the following question: do short recovery times necessarily occur because of (1) increasing populations, (2) high reproductive success, (3) small acute mortalities, or (4) highly variable baseline conditions? The model calculates discounted bird-year loss from Equation 1 using a two life-stage population model (see Caswell, 1997) that operates within a stochastic environment.

The population dynamics of our simulated bird population is determined by:

$$\begin{bmatrix} n_J \\ n_A \end{bmatrix}_{t+1} = \begin{bmatrix} S_J(1 - \tau^{-1}) & S_A F \\ S_J \tau^{-1} & S_A \end{bmatrix} \begin{bmatrix} n_J \\ n_A \end{bmatrix}_t \quad (2)$$

where n_J and n_A are the numbers in juvenile and adult stage classes, respectively, S_J is the annual survivorship of individuals in the juvenile age class, S_A is the annual survivorship of individuals in the adult age class, F is the fecundity of adults surviving to the end of the year (i.e., number of female fledges per female), τ is the average length of the sub-adult age class (in years). These are

similar to the parameters used in the Sperduto et al. (2003) analysis of the *North Cape* oil spill injury. A total population size at any time t (i.e., either NB_t or N_t in Equation 1) is the value of $n_{J,t} + n_{A,t}$ for the relevant baseline (NB_t) or injured (N_t) scenario. This life cycle is depicted in Figure 2a.

To create a stochastic environment, we assume that there are two states of the world (C_t): “good years” ($C_t=1$) and “bad years” ($C_t=0$). If the occurrence of either is correlated with the previous year, we can write the probability of a year being good (versus bad) as:

$$\Pr(C_t = 1) = 1 - p_{00} + [p_{11} + p_{00} - 1] \cdot C_{t-1} \quad (3)$$

where p_{00} is the probability of a “bad year” given the previous year was a “bad year”, and p_{11} is the probability of a “good year” given the previous year was a “good year”. In good years (denoted by subscript G), survivorship and fecundity take on relatively high values ($S_{A,G}$, $S_{J,G}$, F_G). Birds are better able to survive and reproduce. In bad years (denoted by subscript B), survivorship and fecundity take on relatively low values ($S_{A,B}$, $S_{J,B}$, F_B).

Table 1 examines whether population growth and high reproductive success necessarily result in fast recovery times. Entries in Table 1 are the result of 5,000 simulations of the discounted bird-year loss (Equation 1) of removing 1 bird from a population of 100,000.³ Scenarios with high, medium, and low breeding success (table rows) are evaluated in the context of increasing, roughly constant, and decreasing stochastic population trends (table columns). The simulations in Table 1 assume that: (1) in the long run, there are two “good years” for every one “bad year”⁴; (2) juvenile survivorship is half of adult survivorship; (3) birds spend approximately two years in the juvenile age class ($\tau = 2$); (4) initial distribution between juveniles and adults is consistent with the stable age structure implied by the time weighted “average” population

³ In other words, $NB_0 = 100,000$ and $N_0 = 99,999$.

⁴ Specifically, we assume that $p_{00} = 0.50$ and $p_{11} = 0.75$, which results in a 2:1 long-term ratio of good years to bad years.

parameters; and (5) the initial removal of one bird is partitioned between juveniles and adults proportional to their representation in the population. Figure 2b presents an example baseline population trajectory from the case where reproductive success is “medium” and population levels are “roughly constant.”

The results in Table 1 are not consistent with the concept of a “one-year” multiplier, or even a short recovery time. Instead, the discounted bird-year losses range from 26.3 to 69.5 bird-years for the one-bird kills in the table. These multipliers imply recovery times that are considerably longer than those used in bird REAs. In fact, they imply virtually no biological recovery, as losing one bird in perpetuity implies a loss of approximately 33 (discounted) bird-years due to the 3% discount rate. Further, higher reproductive success and population growth do not necessarily produce fast recovery from an injury. Scenarios with increasing populations actually have higher discounted bird-year multipliers than the other scenarios.

Some may find it counterintuitive that Table 1 seems to imply that declining populations have smaller service losses from acute mortality than increasing populations. This occurs in the above model because the area between the injured and baseline trajectories (i.e., the bird-year loss): (1) expands when populations increase; and (2) decreases when populations decline. It is important to remember that “bird-years” of different species (or in different locations) may require profoundly different restoration actions to produce compensation. For example, providing a bird-year of an endangered and declining species may be much more difficult (and costly) than providing a bird-year of an increasing species.

Table 2 shows the results on 5,000 simulations of the effect of population size and baseline variability on bird-year loss calculations. The columns depict scenarios of increasing variability, while the rows show the relative scale of the injury compared to the population size.

For illustrative purposes, we construct the table around the same environmental and demographic dynamics used for the “roughly constant”, “medium reproductive success” scenario in Table 1.

As with the previous set of model runs, none of the scenarios in Table 2 suggest short recovery times. The discounted bird-year loss of removing one bird from the population varies from 33.3 to 37.4, implying virtually no biological recovery. There is no variance in bird-year loss based upon population size, and only small variation in bird-year loss for the scenarios with different levels of baseline variability. As we might expect, we do see increasing variation in bird-year loss estimates where there is more variability in the environment (i.e., Standard Deviation = 4.9 for “low variability” compared to Standard Deviation = 25.0 for “high variability”).

So why are all the recovery times in this model so long? First, the model’s environmental dynamics are exogenous to its population dynamics. In other words, environmental conditions affect the population, but are not affected by the population in turn. If the population increases after an injury due to favorable environmental conditions, it is being compared to a baseline that would also have increased after the spill. In this context, “variability” and “recovery” are separate concepts. Second, the entries of the projection matrix in Equation 2 (i.e., $S_J(1-\tau^{-1})$, $S_A F$, $S_J \tau^{-1}$, S_A) are independent of population levels $n_{J,t}$ and $n_{A,t}$ (i.e., there is no density dependence). This independence implies that injured population levels remain proportional to baseline levels over time. Since injury is defined as the difference between *with* and *without* incident population trajectories, this means that there is no *recovery mechanism* to cause the trajectories to converge (except towards extinction when $n_{J,t} \& n_{A,t} \rightarrow 0$).

The implications of the model results are clear. High reproductive success, high population growth rates, small acute mortalities, and highly variable baseline conditions are not

sufficient conditions for rapid (or any) population recovery based upon a bird-year metric. At best, arguments relying solely on these bases are underspecified. At worst, they may significantly underestimate temporal losses.

ALTERNATE METHODS FOR CALCULATING LOST BIRD-YEARS

We will now look at two general approaches for calculating lost bird-years: one that bases calculations directly on lost individuals (i.e., incident mortality) without explicit consideration of injured and baseline population levels, and another that simulates both baseline and injured population trajectories as done in the above section. We believe that the successful application of either approach depends on the biological rationale describing the mechanism (or lack thereof) by which an impacted population replaces lost individuals.

Direct Calculations of Lost Individuals

The results in Table 2 show that while baseline population variability certainly produces variation in bird-year loss, it does not necessarily have a large impact on *average* bird-year loss. Thus, for some situations, it may be more efficient to focus directly on the factors that might cause the injured population to recover to baseline levels, rather than detailed modeling of injured and baseline population trajectories.

One example of an aggressive recovery mechanism would be if the total production of juveniles is unaffected by the spill. This could occur because non-breeding “floaters” recruit into the breeding class to utilize opportunities (e.g., habitat) that have been made available by any mortality that may have occurred to breeding adults (see Hunt, 1998). This is illustrated in Figure 3 for a hypothetical population with three age classes. Year -1 depicts the population’s pre-spill conditions. Year 0 shows population numbers prior to the first full year after the spill. The shaded area is the number of each age class killed (or absent in future years). The key to the

population's recovery occurs in Year 1, where the number of fledglings completely replaces the losses to the first age class. By Year 3, all of the age classes have been replaced and the population is fully recovered. Under this conceptual framework, a one-year recovery time would only result when losses in the later age classes recover in Year 1. Since birds must survive to reach these ages, full recovery of these age groupings within one year essentially implies *that for every bird killed by the incident, another bird in the wild survives that otherwise would have died.*

Mathematically, the expected total bird-year loss described in Equation 1 would be equivalent to the sum of the (discounted) life expectancy of each age class multiplied by the number of impacted birds that fall in those classes.⁵ In theory, as long as the total juvenile production is the same *with* and *without* the incident, this approach can be applied to either increasing or decreasing populations. Still, it is possible that current population trends are inconsistent with the underlying "recovery mechanism". For example, if a population is experiencing long-term growth while recovering from historically low population numbers, the number of breeders is likely to be increasing over time. The removal of breeding birds may reduce juvenile production in the year(s) following the spill when compared to the growing baseline conditions. This would result in greater bird-year loss than suggested by Figure 3.

We refer to the model in Figure 3 as the "juvenile stepwise replacement approach". It is identical to that used in the *Stuyvesant* Draft DARP (CDFG et al., 2004) and similar to that used for calculating "direct loss" in *North Cape*. Note that in *North Cape* the life expectancies of one additional generation of birds were added to the bird-year losses for some species (Sperduto et al., 1999, 2003). It is difficult, however, to construct a rationale that links population recovery to

⁵ It is also important that the spill not change the juvenile and adult survivorships of the population. Sperduto et al. (1999) provide an example of this calculation, although it is applied to a single "average age" class rather than to each age class individually. This simplification may result in a different estimate of lost bird-years.

a specific number of entirely lost future generations (i.e., if one full generation of offspring is lost, why not the next?). Based on the conceptual framework in Figure 3, recovery is quantified by focusing on the production of juveniles from the remaining live birds rather than what was foregone from the dead birds. One may still posit a slower recovery of the juvenile age class, perhaps because total juvenile production in the following years does not reach baseline levels, but these arguments would be based upon production in “years after spill” and not “generations lost.”

Calculations Simulating Injured and Baseline Population Trajectories

In quantifying lost bird-years, we are primarily interested in the difference between two discrete population levels over time: the population with the spill (injured) and the population without the spill (baseline). Lost bird-years can be measured as the area between two converging lines (as in Figure 1). Since population models are often reasonable tools for describing the dynamics of single species within complex food webs (Murdoch et al., 2002), they can also be useful tools for describing bird-year loss. This is at least partially evidenced by their use to assess the impact of individual spills (e.g., Ford et al., 1982; Swartzman, 1996; CDFG et al., 2004).

The clear advantage of using population models is the ability to explicitly consider injured and baseline conditions, as has been done in the bird-year simulations in the earlier section. From a practical standpoint, population models also provide flexibility to specify recovery mechanisms that are based upon birds remaining in the population. This was done in Ford et al. (1982) where limited foraging resources around breeding rocks provided a mechanism that could produce convergence of injured and baseline trajectories in the long-term (although “bird-years” were not the focus of this analysis). Specifying these types of mechanisms may be helpful for guiding calculations when full juvenile replacement is not necessarily expected.

The same flexibility that makes population modeling attractive can also work against it. Even simple population models may require (or imply) the specification of parameters and relationships that may not be needed when doing direct calculations of lost individuals. On one hand, specifying these relationships may help place the analysis in a broader context (e.g., by helping calibrate appropriate modeling inputs). However, it may also introduce additional uncertainty. Addition of model complexity should be done with care.

It is important to recognize that REA is not fundamentally interested in population trends, but rather the fate of perturbations to those trends produced by individual incidents. From this perspective, convergence of injured and baseline population trajectories (i.e., recovery) requires that the model include some sort of non-linearity (as a necessary but not sufficient condition). We can see that perturbations persist in stochastic environments in the above simulations of a typical linear model. Differences decrease as both trajectories decline, and differences expand as both trajectories increase. These dynamics may be plausible in many cases. Strong (1986), for example, argues that the “density-dependent” mechanisms specified in many non-linear models may only be relevant at population extremes (e.g., either very low or very high population levels). To the extent that more linear dynamics dominate “mid-range” population levels, we may not expect much recovery from individual incidents.

CONCLUSION

The number of birds killed in an incident can be counted or estimated. Lost bird-years, however, are difficult to observe. Attempting to monitor mortality and recovery through population surveys can be problematic because: (1) such surveys inevitably have measurement error, sometimes larger than estimates of acute mortality; (2) surveys cannot simultaneously measure injured and baseline levels; and (3) environmental variability may make it difficult to

define a static baseline. Nevertheless, the simulations and arguments in this paper suggest that removing even a small number of birds from a population can produce persistent impacts.

We believe any attempt to quantify lost bird-years should begin with a biologically-based rationale that explains why an impacted population might recover from an acute mortality event. Without a recovery mechanism whereby the impacted population trajectory converges with the baseline population trajectory, there is no recovery of individuals and killed birds are lost into perpetuity. This is true even if only a small number of birds are killed, if the population is growing or declining, if the species has high fecundity, or if the population experiences high variability.

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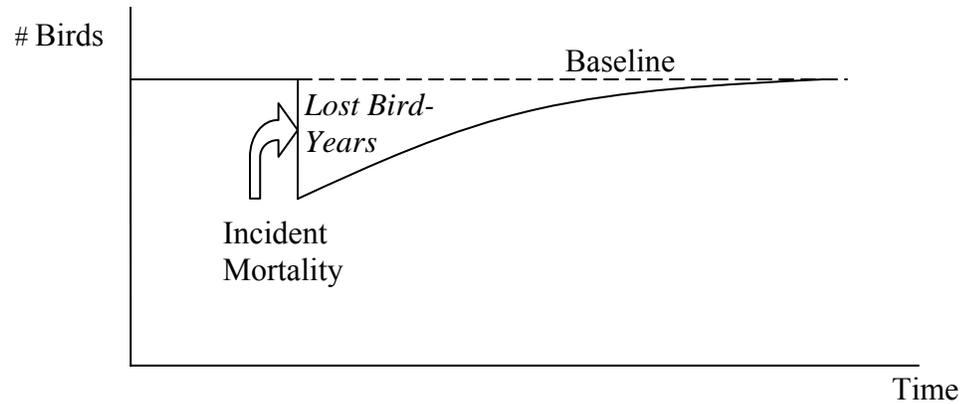


Figure 1. Lost bird-years and recovery to baseline conditions

Table 1.

Simulated Effect of Breeding Success and Population Trend on Recovery Time: Mean Discounted Bird-Year Loss for Removing 1 Bird from a Population of 100,000 (± 1 Standard Deviation)

Reproductive Success (F_G, F_B)	Long-term Population Trend (good-year growth rate, bad-year growth rate)		
	Increasing (0.06, -0.06)	Roughly Constant (0.04, -0.08)	Declining (0.03, -0.09)
High (1.50, 1.0)	69.5 \pm 26.3	34.4 \pm 10.1	26.4 \pm 6.9
Medium (1.0, 0.67)	68.8 \pm 26.0	34.2 \pm 10.0	26.3 \pm 6.8
Low (0.50, 0.25)	69.1 \pm 26.2	34.3 \pm 10.1	26.4 \pm 6.9

Note: $p_{00} = 0.50$, $p_{11} = 0.75$, $\tau = 2$, $S_J = 0.5S_A$, and the remaining biological parameters are determined by the rows and columns of the table.

Table 2.

Simulated Effect of Scale of Mortality and Population Variability on Recovery Time: Mean Discounted Bird-Year Loss (± 1 Standard Deviation)

Relative Scale of Mortality	Baseline Variability (good-year growth rate, bad-year growth rate)		
	Low Variability (0.02, -0.04)	Moderate Variability (0.04, -0.08)	High Variability (0.08, -0.16)
1 out of 1 billion	33.3 \pm 4.9	34.2 \pm 10.0	37.4 \pm 25.0
1 out of 100,000	33.3 \pm 4.9	34.2 \pm 10.0	37.4 \pm 25.0
1 out of 100	33.3 \pm 4.9	34.2 \pm 10.0	37.4 \pm 25.0

Note: $p_{00} = 0.50$, $p_{11} = 0.75$, $F_G = 1.0$, $F_B = 0.67$, $\tau = 2$, $S_J = 0.5S_A$, and the remaining biological parameters are determined by the columns of the table.

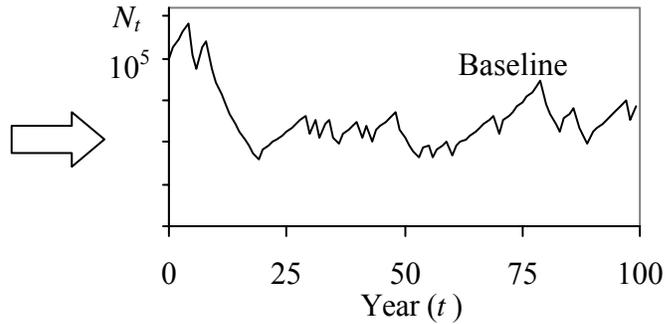
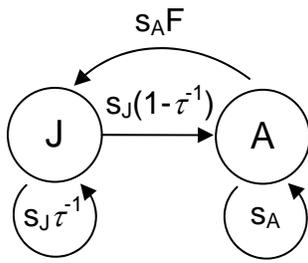


Figure 2a. Life cycle graph for simulated population (J = Juvenile; A = Adult)

Figure 2b. Example baseline population trajectory from a “Medium Reproductive Success, Roughly Constant Trend” scenario in Table 1

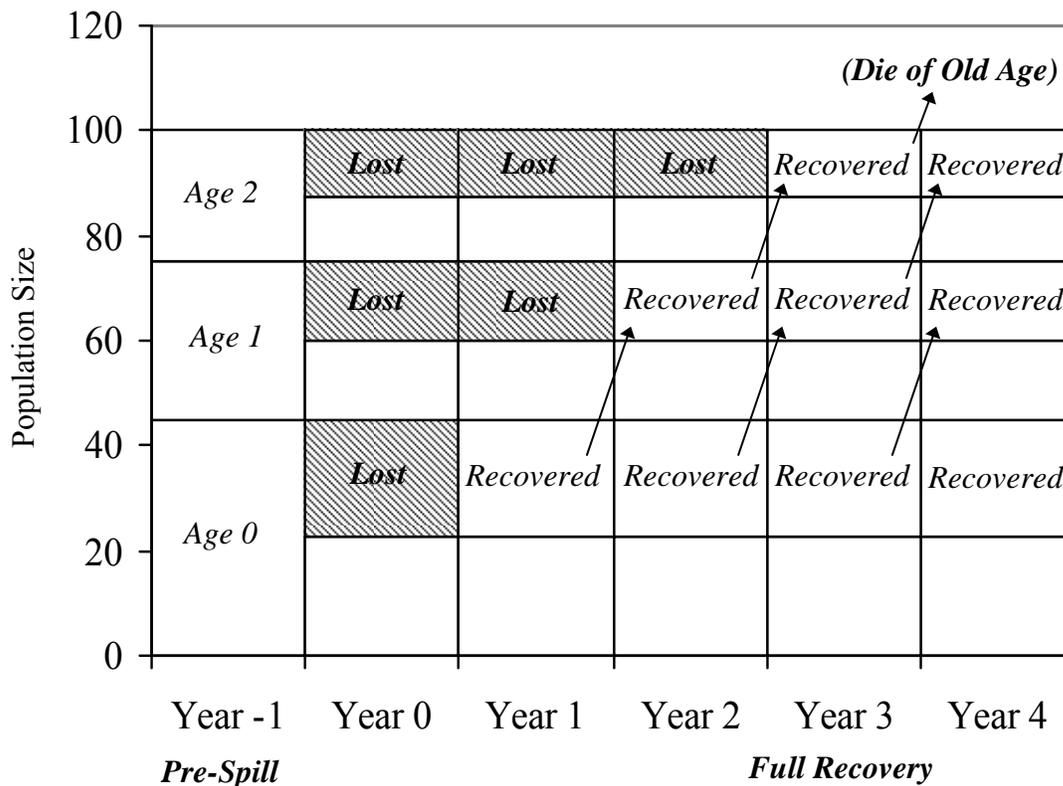


Figure 3. Example bird-year losses with full replacement of the juvenile age class in the year after the spill