"How much is enough?"

Determining adequate levels of environmental compensation for wind power impacts using equivalency analysis: An illustrative & hypothetical case study of sea eagle impacts at the Smøla Wind Farm, Norway

Abstract

Environmental considerations at wind power developments require avoidance and mitigation of environmental impacts through proper citing, operational constraints, etc. However, some impacts are unavoidable for otherwise socially-beneficial projects. Criteria for Environmental Impact Assessment (EIA) suggest that compensation be provided for unavoidable or residual impacts on species and/or habitat from wind power development. Current environmental compensation schemes for wind power fail to demonstrate a connection between the expected ecological damage and the ecological gains through restoration. The EU-funded REMEDE project developed quantitative methods known as "equivalency analysis" to assist Member States in implementing EU Directives that require scaling of environmental compensation. This study provides a transparent framework for estimating compensation at wind facilities based on the REMEDE approach. I illustrate the approach with a hypothetical case study involving sea eagle impacts at the Smøla Wind Farm (Norway). This study assumes measures be will implemented to alleviate future impacts on the eagle population but that an interim loss of resources to the public remains. I illustrate how one could quantify the damage (debit) from sea eagle turbine collisions. A potentially-promising compensatory project that reduces eagle mortality from power line electrocution is suggested to generate the environmental gains (credit), which is quantified using hypothetical data. Pending completion of on-going research, this framework could be applied with actual data to inform future compensation at Smøla. The framework is generalizable to on- and off-shore wind development but requires targeted and thoughtful data collection. Importantly, compensation should not be used disingenuously to justify otherwise environmentally costly projects.

Keywords: Equivalency Analysis, environmental compensation, wind power

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This paper was originally published in the Proceedings of the European Offshore Wind 2009 Conference in Stockholm, Sweden (September). It was later revised for publication in a Licentiate Thesis at the Swedish Agricultural University. That thesis can be found here: http://diss-epsilon.slu.se:8080/archive/00002281.

This paper should be cited as follows:

Cole, Scott. 2010. *How much is enough? Determining adequate levels of environmental compensation for wind power impacts using equivalency analysis: An illustrative & hypothetical case study of sea eagle impacts at the Smøla Wind Farm, Norway*. Epsilon Open Archive Publishing, Swedish Agricultural University. Available on-line at: http://pub-epsilon.slu.se:8080/

1 Introduction

Environmental considerations require avoidance and mitigation (or minimization) of environmental impacts (proper citing, operational constraints, etc) when citing wind power facilities. To this end, many countries have developed "sensitivity mapping" to avoid the most sensitive species and habitats areas [1]. However, some impacts are unavoidable for otherwise socially-beneficial projects. In a typical Environmental Impact Assessment (EIA) impacts that cannot be avoided or mitigated can sometimes be addressed through environmental compensation measures.[1] For example, several wind energy development guidelines [2,3,4] suggest that developers follow the "Avoid-Mitigate-Compensate" hierarchy which recommends that compensation measures are utilized only after alternative designs or mitigation are shown to be ineffective for an otherwise favorable project alternative.

There is a strong need for improved quantitative methods to scale environmental compensation for development projects.[2] Current environmental compensation schemes for wind power projects fail to demonstrate a connection between the projected (or real) ecological damage and the ecological gains expected through restoration actions (e.g., compensation). For example, scaling of some compensation measures in California are based on the total generating capacity or wind-swept area of a turbine rather than an environmental metric that quantifies environmental loss and gain [6]. Compensation should, instead, be based on a transparent scientific method. The EU-funded REMEDE project (www.envliability.eu) developed quantitative

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[1] The term environmental compensation refers to restoration projects that improve a resource or service for the public. It does not refer to financial compensation.

[2] See delays associated with compensation for Sweden's Botnia Railroad project [5].

methods known as equivalency analysis to assist Member States in implementing EU Directives that require compensatory restoration[3] for environmental damage. These methods are described in the REMEDE Toolkit [7]. The purpose of compensatory restoration is to ensure the public's loss of environmental resources or services (debits) are offset through the restoration, rehabilitation, or enhancement of resources/services of a similar type and quantity (credits). Restoration may be appropriate prior to a project (ex ante) or after environmental contamination (ex post).

This study will develop a framework for environmental compensation at wind farms based on the Toolkit's equivalency analysis method and illustrate this approach hypothetically for the Smøla wind farm in Norway. The wind farm, which is owned by the National Power Company in Norway known as Statkraft, began operation in 2002 and by 2005 included a total of 68 land-based wind turbines [8,9]. Between 2005 and 2009, at least 26 sea eagles have died due to collisions with the turbines [10,11,12]. The high rate of collision mortality is somewhat rare among avian studies of wind power projects [13,14], although raptor collisions with turbines have been documented in several countries.[4] In 2006, following collection of dead sea eagle carcasses under turbines, Statkraft funded a four-year research project managed by the Norwegian Institute for Nature Research (NINA) [19], to better understand the causes of bird-turbine collisions in general and to better inform the planning of future wind turbines. This study, which develops a framework for wind power compensation measures, is funded by the Swedish Environmental Protection Agency [20], but considers research being conducted by NINA.

While compensation for wind power's environmental impacts have occurred in Scotland and the US, among other places [21,22], rarely have the impacts been quantified using an environmental metric, or the compensation scaled to match the size of the damage. The EU's REMEDE approach based on equivalency analysis -- which is used extensively in the US to compensate the public for environmental losses arising from oil and chemical spills or other human-induced

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[3] I use the word restoration to refer to a compensation action. The REMEDE Toolkit uses (complementary or compensatory) remediation to refer to the same idea.

[4] Raptor collisions are documented in Sweden [15,16,17], Germany [18], US [6] and Spain [14].

environmental damage[5] [23-28] -- represents a quantitative, consistent and transparent framework for informing compensation at wind farms. In doing so, the approach provides a rough approximation of lost resource value based on the costs to restore similar resources (see Step Four).

The provision of environmental compensation for wind power development may increase for several reasons. First, the number of project proposals in Europe has increased dramatically in recent years. Whether these projects are (1) built or (2) require compensation, depend on a number of variables. However, the pressure to offset environmental impacts may increase as less ideal sites are developed for wind energy. Second, power companies that sell "green-labeled" electricity may wish to lessen the environmental impact of their product. Compensatory restoration at wind farms -- in conjunction with the CO_2 emissions benefit -- could provide a more convincing environmental argument for their product.[6] Thirdly, while most countries have signed agreements to reduce CO_2 emissions, countries have also signed international agreements aimed at slowing the loss of biodiversity, which may conflict with wind power development in terms of species and habitat loss. For example, Norway is part of the EU quota system for CO_2 reduction as well as the Convention on Biological Diversity [29,30].[7] Thus, environmental compensation for wind power impacts may provide an opportunity for countries to achieve both environmental goals simultaneously.

The remainder of this paper is structured as follows: After a description of the compensation framework based on equivalency analysis, I illustrate its application to the Smøla wind farm. While data are not yet available to provide definitive conclusions regarding the extent of compensation at Smøla, the case study provides a concrete - if hypothetical - example of how to quantitatively assess the extent of damage and to determine a reasonable amount of compensation credit.

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[5] I am unaware of resource equivalency analyses applied to wind power projects. While the pathway of bird injury differs with turbine collisions, the equivalency framework remains unchanged.

[6] Sweden's "bra miljöval" program certifies "green" electricity produced from wind power if it is not developed in bird migration areas or high quality habitat [31]. The program does not currently consider environmental gains associated with compensatory restoration measures.

[7] Norway's report on the management of biodiversity notes: "It is important to ensure the expansion of wind and water power happens without negative effects on natural diversity ..." (see [30] p. 87).

The paper concludes with some key findings (including a discussion of costs) and discusses the limits of equivalency analysis.

1.1 REMEDE Toolkit approach to environmental compensation[8]

The EU's Environmental Liability Directive (ELD) [Directive 2004/35/EC] entered into force in 2007. Although the ELD does not cover the environmental impacts of wind power facilities, it is relevant because it was the first Directive to explicitly identify a framework for environmental compensation. It requires that damage be restored [remediated] so that the affected environment returns to (or toward) its baseline condition and that the public is compensated for the initial damage and the losses during the time the environment takes to recover (interim losses). To inform compensation in practice, the European Commission funded the REMEDE research project (Resource Equivalency Methods for Assessing Environmental Damage in the EU). The result was the 2008 REMEDE Toolkit [Lipton et al 2008] which explains the use of equivalency analysis (also called resource equivalency methods) as the preferred approach for scaling the amount and type of compensation for environmental damage in Europe (applicable under a variety of Directives[9]). The REMEDE Toolkit identifies five basic steps in implementing an equivalency analysis:

- Step One: Initial evaluation
- Step Two: Determine the environmental damage (debit)
- Step Three: Determine the environmental gains from restoration (credit)
- Step Four: Scale restoration ("how much is enough?")
- Step Five: Monitoring and reporting

Given a case of environmental damage requiring compensation, equivalency analysis answers two questions: (1) how much of a resource/service was damaged? and (2) how much of a resource/service should be restored? Figure I-1 illustrates the case of environmental damage, known as the debit, and Figure I-2 illustrates

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[8] This section draws upon [32] to provide a simplified explanation of the REMEDE Toolkit for the purpose of this particular case study. More info in [7].

[9] In addition to the ELD, see also Habitat and Wild Birds and Environmental Impact Assessment Directives (see www.envliability.eu).

the case of environmental restoration, known as the credit. The objective is to measure the size of the debit (loss) and credit from restoration (gain) and ensure they are "equivalent" over time, thus compensating the public for resource loss.

Figure I-1: Anatomy of environmental damage (debit)

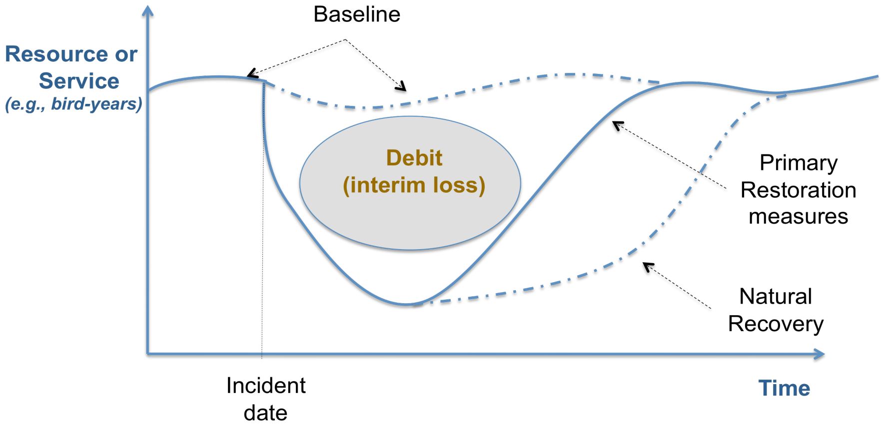

Figure I-1 shows a stylized picture of environmental damage over time (Step Two). The y-axis measures the quality and/or quantity of an impacted resource or service. It can be measured in any metric, including money. In this study I use "bird years" (see more below). Importantly, an environmental metric provides a proxy to measure the change (loss or gain) in the level of environmental services or the quality/quantity of a resource. The x-axis shows the change in the quality/quantity of the impacted resource/service over time. Figure I-1 shows an incident date, the beginning of some environmental loss. The first solid, then dashed, line at the top shows the baseline, which reflects the condition of the resource/services had the damage not occurred and illustrates when recovery of a damaged resource is complete. For example, the environmental loss (debit) stops accruing when the resource has returned to its baseline level through natural recovery or some active measure. In this case, I assume primary restoration measures are actively taken to reach baseline. These measures -- such as turning off turbines during high eagle activity[10] -- are aimed at reducing bird collisions and to return to (or toward) baseline. The key implication of Figure I-1 is that even if primary restoration is implemented, an interim loss (shaded area) has accrued to the public over time because the quality/quantity of the resource has declined. The REMEDE approach provides a method for ensuring the public is compensated for this interim loss.

Given a quantitative estimate of the size of the damage (debit), the second question can be addressed: how much restoration (credit) do we need to compensate the public for this damage? The compensation provided to offset the interim loss in Figure I-1 is referred to as compensatory restoration,[11] which is a restoration project that provides quantifiable gains in the resource that was damaged. In this case, projects that produce "bird years." An illustration of the concept of producing "bird years" is shown in Figure I-2.

Figure I-2: Anatomy of environmental gains (credit)

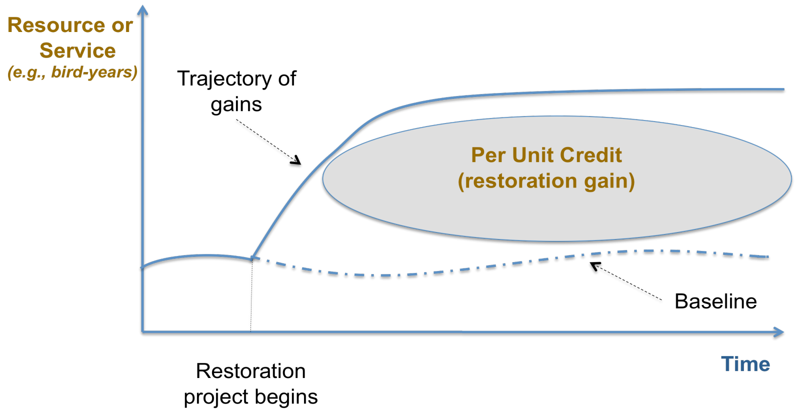

Figure I-2 measures the environmental gain per unit in quality and/or quantity of a resource/service over time (Step Three). The Y-axis is measured in the same metric that was used to proxy the level of

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[10] Researchers are investigating possible primary restoration measures at Smøla, see [19].

[11] REMEDE distinguishes between complementary and compensatory restoration [remediation]; the former is when a resource never returns to baseline. I focus only on compensatory restoration.

environmental services in Figure I-1 (in this case "bird years"). Further, the credit is measured on a per unit basis (e.g., per acre restored, per nest protected, per utility pole retrofitted, etc), which allows us to "scale" the correct amount of restoration in Step Four. A restored resource is assumed to have a trajectory of gains, starting when the restoration project begins. The baseline is important because it describes the condition of the resource prior to undertaking the restoration (e.g., highly functioning ecosystems leave less room for gains). In Figure I-2, the baseline is assumed to provide some non-zero level of environmental services.

Step Four ensures equivalence between the total debit and the per unit credit. To determine "how much is enough," simply divide the total debit by the per unit credit, which is referred to as scaling. By virtue of the polluter pays principle - which underlies EU Directives covering compensation - compensation should be paid by those causing the damage.

The issue of timing in equivalency analysis is key because the debit and credit frequently occur at different times (e.g., debits may occur in the past and future, while the credit generally occurs in the future). Economists argue that the timing at which we are able to consume goods -- environmental or private -- affects the value we hold for them: we prefer to consume "good" things today rather than tomorrow (and vice versa for "bad" things). Economists refer to this inherent human "impatience" for consuming as a positive time preference, see [33]. Thus, we need a procedure to ensure that debits and credits that occur at different times are compared (valued) on an equal basis. To do this, I apply a present value multiplier to the value of debits and credits, based on an assumed discount rate (I use three or six percent as discussed below). The implication is that the bird years lost or gained in the future are worth less to us -- not only are we impatient, but the future is uncertain and we might not be around to enjoy the birds. [12]

Finally, the damaged resources and the restored resources are sometimes of differing quality or in different locations. The goal of compensatory restoration is to provide a similar type, quality, or quantity of a resource or service. The key assumption in equivalency

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[12] Consider hypothetical project A that "saves" a bird in 2009 and project B that "saves" a bird in 3009. If we assume project costs are the same (in present value terms), then a positive discount rate (impatience) would argue logically for choosing project A. In contrast, a zero discount rate gives a counter-intuitive outcome: both projects have the same "value" and we flip a coin to decide.

analysis is that we (humans) can restore, create, engineer, rehabilitate, or improve ecosystems -- even if our "restored systems" are not perfect replicas of the original. While some take issue with this underlying assumption [34,35], the well-established use of equivalency analysis in the US -- as well as the anticipated use in Europe given the REMEDE Toolkit -- demonstrates its credibility as an approach for quantifying compensation.

1.2 Case study illustration: Smøla wind farm

The rest of this paper provides a hypothetical illustration of this framework for the Smøla wind farm.

1.2.1 Step One: Initial Evaluation

The initial evaluation at Smøla includes background information on the sea eagle population, the wind farm study area, as well as a preliminary review of damage and possible restoration options.

Sea eagle population. The white-tailed sea eagle, or sea eagle, (*Haliaeetus albicilla*) has about 5,000 to 6,600 breeding pairs in Europe, representing 50 to 75 percent of the global population [36]. Approximately 3,500 - 4,000 mating pairs are estimated in Norway making it the largest national breeding population in Europe [37]. While the sea eagle population in Europe has suffered from direct persecution (hunting) and contamination from pesticides throughout the 20th Century, it has made a comeback in the last 30 years with increased population growth in all areas except Eastern Europe. Despite bounty hunting in the 1960s, the Norwegian population has fed off relatively uncontaminated food resources and avoided the near population crash in the rest of Europe [38].

The sea eagle population resiliency has allowed for successful re-colonization of previously lost territory [39,40] which, in part, led to the species' down-listing from "near threatened" in 1988 to "least concern" in 2005 by the International Union for the Conservation of Nature [41,42]. On-going threats to the species in Norway include (1) wind farm development; (2) electrocution from overhead power lines; (3) loss of habitat due to human development (roads, summer houses, energy extraction, etc); (4) lack of legal protection for nesting sites, particularly forestry and industrial activity in Norway;[13] (5) disturbance during breeding from increased recreational activity; and (6) lead poisoning from ingestion of prey containing ammunition [42-46,37].

Smøla Wind Farm and Study area. The study area (see map Appendix A) includes the archipelago region on the mid-west coast of Norway, west of Trondheim. The collection of islands known as Smøla lies 10 km off the coast with a total land area of 274 km2. Phase I of the Smøla wind farm was permitted in 2001 and officially opened in September 2002 with 20 turbines (installed capacity of 2.0 MW per tower). Phase II opened in September 2005 with 48 additional turbines (installed capacity of 2.3 MW), leading to a total project footprint of 18.1 km2 of previously undisturbed land (including 28 km of roads). The turbines are placed on ridges (10 to 40 meters above sea level) along the island. At an estimated annual power production of 420 GWh it is Europe's largest land-based wind farm [8,9].

Extent of Damage. A key step is a preliminary determination of whether environmental damage is "significant" enough to warrant compensation. Lipton et al [7] provide some guidance, but the decision should be made on a national level. If the study was actual instead of hypothetical, I would motivate compensation at this location based on a review of the ecological evidence. In the case of Smøla I may, for example, point to the following: (1) rarity of the Smøla habitat, which has the world's highest breeding density of sea eagles [47,44]; (2) sea eagle mortality from turbine collisions from 2005-2009; (3) a vulnerable species with high annual survival but low reproductive output. Such characteristics make it difficult to compensate for increased adult mortality [48]; (4) ecological importance of the species. Studies have suggested that sea eagle populations act as "environmental sentinels;" i.e., a stable population can be monitored to identify ecosystem threats early and avoid costly environmental restoration later [49]; and (5) Norway's role as stewards of the sea eagle population. From a European point of view, Norway may have a special responsibility to protect the species in part because the country supports 45 percent of the European population as of 2001 [47]. In general, compensation may be justifiable when cumulative impacts from human disturbance are unmeasured but potentially high, as in this case. As history demonstrates, significant fluctuations in the sea

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[13] While most European countries have legal protection for nesting sites, Norway does not [37].

eagle population are directly linked to human activity. Current development pressures may perpetuate these fluctuations in the absence of reasonable compensation measures to ensure a stable sea eagle population.

Identification of potential restoration projects. Table I-1 identifies a list of compensatory restoration projects that may provide environmental gains (credits) for sea eagle populations by (1) reducing threats to the species, (2) increasing breeding success or (3) increasing breeding opportunities. These projects - considered further in Step Three -- are based on factors that are currently limiting the sea eagle population according to the Species Action Plan [43]. This non-exhaustive list provides an overview of the types of projects for which compensation credits can be estimated and scaled to offset environmental debits.

Table I-1. Identification of potential restoration projects to address sea eagle debits
• Retrofit power lines to reduce sea eagle mortality from electrocution (on/offsite)
• Purchase, restore, or improve sea eagle habitat in Norway that is currently threatened by development or otherwise unsuitable for sea eagle production (offsite)
• Build or enhance sea eagle nests in Norway in areas limited by nesting opportunities (offsite)
• Purchase, restore or improve sea eagle habitat, or build/enhance nests outside of Norway[14] (e.g., in Eastern European countries where the population is declining)
• Fund measures to reduce mortality associated with train and/or car collisions (on-/offsite)
• Fund research to identify successful strategies for reducing sea eagle mortality from a variety of human activities (e.g., fill the knowledge gap needed to quantify environmental gains)
• Re-introduce sea eagles into previously colonized areas (in Europe or Globally) where populations are currently extirpated (assuming conditions have improved since extinction)
• Fund an outreach program to educate hunters on the dangers of lead ammunition in carcasses fed on by sea eagles; alternatively, fund a campaign to ban lead ammunition (on-/off-site)

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[14] A California oil spill resulted in restored habitat in New Zealand to compensate for a migratory bird species injured by the spill [24].

1.2.2 Step Two: Determine environmental damage (debit)

In this Step, I identify an environmental metric to measure loss/gain and motivate assumptions for the hypothetical interim loss calculation (debit). I focus on sea eagles, assuming it is an indicator for overall ecosystem health at Smøla. That is, the goal is to measure "environmental damage" in a broad sense but I base the quantitative analysis on the sea eagle population. [15]

Environmental Metrics. Given the focus on sea eagles, I need to measure how they are impacted by the wind farm. To do so I select an environmental metric -- a "currency" to measure debits and credits. Rather than counting individual birds lost/gained, I will measure "Bird Years" (BYs) which accounts for the species' life history characteristics (Table I-2). A Discounted Bird Year (DBY) measures the life expectancy of a bird (either from birth, or from the time of collision, etc) in today's value based on an assumed discount rate. The DBY metric is beneficial because (1) it accounts for the value of impacts occurring at different times by discounting; (2) it accounts for possible disparity in age between injured and restored birds (e.g., collided birds may be older/younger than birds produced from restoration) [27]; (3) it assigns a higher weight (e.g., more BYs) to adults, which is consistent with the fact that adult sea eagles are ecologically valuable from a population point of view[16]; and (4) it allows us to add direct and indirect components of the debit (i.e., mortality and foregone production) and credit (i.e., avoided mortality and avoided foregone production).

The annual adult and juvenile survival rates in Table I-2 represent a key assumption underlying my calculations in the appendices. The numbers are based on a 2009 study of re-introduced sea eagles in Scotland [50] which found that survival rates were similar to those recorded elsewhere. A study of sea eagles in Norway from 2000 used long-lived radio tags to track birds and estimated survival rates for the first two years of life to be between 90 and 95 percent [70]. Further, a study of sea eagles along the Swedish coast between 1975-1981 based

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[15] Preliminary data from NINA's project at Smøla [19] indicate that mortality from collision has affected 18 other bird species (totaling 61 individuals) between 2003 and 2008, Table 2 in [10].

[16] By valuable we mean that a 1 year old bird is not contributing to the population (does not reproduce) and has a relatively small chance of surviving to the next year, whereas a 7 year old bird is reproducing and has a relatively greater chance of surviving to the next year, compared to the 1 year bird.

on ringed breeders indicates that minimum annual survival rates averaged 90% (ages 2 to 6), 98% (age 6 to 11), 94% (ages 11 to 16) and 91% (ages 16 to 21) [69]. Even newer and more site-specific data are expected from the ongoing research project on Smøla [19]. Finally, productivity (no. of offspring per pair) is used in the calculation of indirect losses in Tables I-3 and I-4 (see also Appendix E).

Table I-2. Species Life History Characteristics used in DEBIT and CREDIT calculations

Age of first production of offspring (fecundity)	5 years
Maximum age of reproduction	30
Annual juvenile survival rate (Years 1,2,3,4)	82%,82%,86%,95%
Annual adult survival (Years 5 through 30)	97%
Estimated average age of the population (Appendix B)	13
Productivity (no. of offspring per pair) [73]	0.46
Source: [50]. Characteristics assume a growing population (i.e., multiplier factor = 1.097)	

Calculating the Debit. There are three potential sources of lost BYs from the wind farm: (1) direct losses from collision mortality (2) indirect losses from production forgone due to parents that collided and (3) indirect losses from reduced reproductive success for pairs that remain in the wind farm area, but are disturbed by power production.[17] Below I quantify the first two categories of losses. The third category assumes a reduction in reproductive success after the wind farm compared to before the wind farm. Because definitive conclusions regarding this hypothesis are still being tested (results expected by 2011) these BY losses are not included in the calculations.

Table I-3 shows the calculation of DBYs lost from the wind farm in this hypothetical case study. The purpose is to demonstrate the use of "DBYs" as a metric to measure and quantify the interim loss (debit). Direct impacts from collision mortality are shown in Column E. These

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[17] Some birds may re-locate to new territories to avoid disturbance from the wind turbines. Such relocations would not be considered losses if they produce at least as well as they did at Smøla.

lost BYs are based on how much longer an average-aged bird that collides would have lived if it had not collided in a given year. The value of this BY loss is discounted to the year of the analysis (2009) to obtain DBYs. Indirect losses from production forgone due to these collisions are shown in Column G. These losses are based on the BYs that would have been "produced" (e.g., offspring) by an average-aged sea eagle from age of collision until maximum age, discounted to 2009. The total debit sums these two categories of losses in Column H (detailed calculations in appendices).

I assume the losses from 2005 to 2009 (26 collided birds) will continue at the same average rate: 5 per year. I assume primary restoration measures are undertaken in 2013 that return the resource to baseline by 2018 (e.g., 0 collisions). I present an alternative that assumes recovery occurs at the end of the project's permitted life, 2027. A social discount rate of three percent is used to reflect society's time preference. The US regulations for assessing environmental injury recommends the use of a three percent rate. I conduct a sensitivity analysis using six percent based on guidelines from the Norwegian Government Agency for Financial Management (SSØ) for energy-related projects affecting the public interest [51,52].

Despite the return to baseline due to assumed primary restoration measures, an interim loss has accrued to the public which I value at approximately 1,500 to 2,000 DBYs, depending on the assumed discount rate. If collisions continue over the life of the project (until 2027), total losses increase to approximately 2,500 and 3,300 DBYs.

Table I-3. Total discounted losses (debit) from turbine mortality and production foregone - hypothetical calculations

Year	Discount Factor	No. of bird collisions	Life expectancy for birds that collide	Discounted loss from collision mortality (*direct*)	Production foregone per collided bird	Discounted loss from production foregone (*indirect*)	Total debit from wind farm (DBYs)
A	B	C	D	E	F	G	H
	formula[a]	assumption	Appendix C	E=B*C*D	Appendix E	G=B*C*F	H=E+G
2005	1.13	4	10.5	47.3	26.1	117.7	164.9
2006	1.09	6	10.5	68.8	26.1	171.4	240.2
2007	1.06	2	10.5	22.3	26.1	55.5	77.7
2008	1.03	9	10.5	97.3	26.1	242.3	339.6
2009	1.00	5	10.5	52.5	26.1	130.7	183.2
2010	0.97	5	10.5	51.0	26.1	126.9	177.8
2011	0.94	5	10.5	49.5	26.1	123.2	172.7
2012	0.92	5	10.5	48.0	26.1	119.6	167.6
2013	0.89	5	10.5	46.6	26.1	116.1	162.8
2014	0.86	4	10.5	36.2	26.1	90.2	126.4
2015	0.84	3	10.5	26.4	26.1	65.7	92.0
2016	0.81	2	10.5	17.1	26.1	42.5	59.6
2017	0.79	1	10.5	8.3	26.1	20.6	28.9
2018	0.77	0	10.5	0.00	26.1	0	**0.0**
Total to 2018 (6%)		56		571 (455)		1,422 (1,080)	**1,994 (1,535)**
Total to 2027 (6%)		101		1,060 (861)		2,275 (1,567)	**3,336 (2,428)**

[a] Discount factor formula in Appendix C; base year is 2009. Figures in Columns D and F are discounted to the year of collision and year of birth, respectively. Total impacts in Columns E and G are discounted to the base year of the analysis (2009). Calculations shown in Appendices. Totals differ due to rounding

1.2.3 Step Three: Determine environmental gains (credits)

In this Step, I illustrate how to quantify the environmental gains from a restoration project to offset debits from the wind farm. The goal is to quantify the number of years that birds produced (or "saved") by a restoration project are expected to live, i.e., the "compensation credits" in DBYs.

Several compensatory projects could be considered based on (1) synergies with local land management plans and species action plans, (2) current research (3) data availability (4) effectiveness of restoration (5) cost, etc. All projects identified in Step One could be investigated and scaled using equivalency analysis, but some may be eliminated during this iterative process. I select one project - power line retrofitting - to illustrate how to quantify compensation credits. While information is not currently available to quantify the credits from power line retrofitting, such data are expected in the near future.[18] Therefore, I use hypothetical numbers in the calculations below, which can be replaced with actual data when available.

Problem Description: Sea eagle electrocution is well-documented in Norway and other countries [53-56,48]. Electrocution of large raptors like sea eagles is due to the combination of the species' tendency to perch on top of utility poles while hunting and their long wings which span across multiple cables or transmission points. The bird closes the circuit when simultaneously touching two electrified parts of the structure, leading to death. The impact on sea eagles varies depending upon pole design and location, topography, species behavior etc. Smaller distribution lines (<120 kV) are the most dangerous.

Restoration Project - Retrofitting utility poles to reduce electrocutions. Electrocution can be prevented by installing devices that insulate dangerous structures, re-designing utility poles to deter birds from perching, increasing the distance between wires, replacing top mounted isolators on the cross-arm with hanging isolators, etc. In

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[18] To quantify the gain in BYs from such measures, I must identify how many birds die each year from electrocution and estimate the effectiveness of measures against mortality. On-going research is attempting to address these questions for a variety of bird species [58].

some cases, wires may be laid underground but at a greater expense [57,59].

Why retrofitting? The characteristics of the problem lend itself to be an ideal compensatory restoration project for wind power projects that cause bird loss. First, there is a natural link between power generation (wind) and power distribution (power lines) that would facilitate cooperation in developing compensation credits. Second, in contrast to turbine collisions, the causes -- and prevention -- of bird electrocution are well-understood thanks to an extensive literature dating to the 1970s. Third, a review of the literature indicates that electrocution is a more common cause of death than turbine collisions,[19] which suggests a potentially large pool of BYs from which one can derive compensation credits. Finally, despite available technological solutions, very little progress has been made in reducing raptor electrocutions due to funding constraints [58,60,55,61]. In summary, utility pole retrofitting is an ideal compensatory project because it matches a wind power company seeking compensation credits with power distributers who are underfunded -- yet pressured -- to address a "fixable" problem.

Finally, some argue that dangerous poles should be retrofitted regardless and that wind power companies should not receive "credit" for something utility companies should undertake independently. For example, the Bern Convention's Recommendation 110 [59], published in 2004, details electrocution prevention measures that several countries (including Norway) have agreed to carry out. In practice, however, implementation of these readily-available technical solutions is very limited. I argue that the possibility of "compensation credits" for wind power companies provide an impetus for implementing the Bern Convention Recommendation and to achieve real environmental gains for bird populations, while ensuring public compensation for lost resources.

The "hypothetical" illustration - Calculating the per unit credit from retrofitting. Retrofitting measures will reduce sea eagle mortality, leading to a quantifiable increase in DBYs by (1) directly avoiding deaths from electrocution and (2) indirectly avoiding production losses (offspring).

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[19] An inescapable caveat to the literature is that cause of death is heavily biased because studies only include "discovered" bird carcasses, rather than all victims from a systematic search.

Table I-4 shows the calculations for DBYs gained for each utility pole retrofitted in this hypothetical case study (to save space I display only the first five years and then the final years). The objective is to demonstrate how to quantify the per unit credit from restoration. Direct gains from avoided electrocution mortality are shown in Column E. These credits are based on how much longer an average-aged bird would have lived if it had not been electrocuted in a given year, discounted to the year of the analysis (2009). Indirect gains from avoided production losses are shown in Column G. These credits are based on the DBYs that would have been "produced" (offspring) by an average-aged eagle from the age of electrocution until maximum age. The total credits per utility pole retrofitted is the sum of these two categories, Column H (detailed calculations in Appendices).

For illustration, I assume the retrofitting of an individual utility pole leads to .01 fewer electrocution deaths per utility pole, per year (the actual number will be based on documented studies not yet complete). I assume the project benefits are provided each year from 2012 until 2037, i.e., a 25 year project life. I show a sensitivity analysis assuming 100 years. As above, a discount rate of three (and six) percent is used to reflect society's time preference.

For each utility pole retrofitted, approximately 6 DBYs are generated over a 25 year project life, or approximately 11 DBYs if benefits continue over 100 years. By assuming a higher discount rate of 6 percent (future gains are worth less), per pole credits are 3 to 4 DBYs (25 and 100 years, respectively).

Table I-4. Total discounted gains (credit) from avoided electrocution and avoided production losses per utility pole retrofitted - hypothetical calculations

Year	Discount Factor	No. of avoided electrocutions per pole per year	Discounted life expectancy gain per avoided electrocution	Credit from avoided electrocution (*direct*)	Production per avoided electrocution	Credit from avoided production loss (*indirect*)	Total per pole credit from retrofitting (DBYs)
A	B	C	D	E	F	G	H
	formula[a]	assumption	Appendix C	E=B*C*D	Appendix E	G=B*C*F	H=E+G
2012 (1)	0.92	0.01	10.5	0.10	26.1	0.24	**0.34**
2013 (2)	0.89	0.01	10.5	0.09	26.1	0.23	**0.33**
2014 (3)	0.86	0.01	10.5	0.09	26.1	0.23	**0.32**
2015 (4)	0.84	0.01	10.5	0.09	26.1	0.22	**0.31**
2016 (5)	0.81	0.01	10.5	0.09	26.1	0.21	**0.30**
...	...	...	...	...	...	...	...
2037 (25)	0.44	0.01	10.5	0.05	26.1	0.11	**0.16**
...	...	...	...	...	...	...	...
2112 (100)	0.05	0.01	10.5	0.00	26.1	0.01	**0.02**
Hypothetical total over 25 yrs to 2037 at 3% (totals at 6%)				1.77 (.99)		4.40 (2.34)	6.17 (3.33)
Hypothetical total over 100 yrs to 2112 at 3% (totals at 6%)				3.13 (1.26)		7.80 (2.99)	10.93 (4.25)

[a] The formula for the discount factor is 1/[(1+r)current yr - base year], where r is assumed to be 3 (or 6) percent and the base year is 2009. The year 2037 represents 25 years from beginning of project; year 2112 represents 100 year project life.

Columns D and F are discounted to the year of electrocution and year of birth, respectively. Total impacts in Columns E and G are discounted to the base year of the analysis (2009). Totals may differ slightly due to rounding

1.2.4 Step Four: Scale Restoration ("how much is enough?")

Scaling restoration refers to the process of determining how much compensation is required to ensure the public is adequately compensated for the loss of a resource. Equivalency analysis asserts that it is a function of: (1) the size of the environmental damage and (2) the per unit environmental gains from restoration. To ensure "equivalence" divide total debits by per unit credits.

Given hypothetical numbers in Tables I-3 and I-4 (discounted at three percent), approximately 180 utility poles (1,994/10.93) would need to be retrofitted, assuming damages from the turbines last until 2018 and environmental gains from retrofitting last a full 100 years. Alternatively, if damages last until 2027 but environmental gains last 25 years, then retrofitting 540 utility poles (3,336/6.17) would provide enough scaled compensation to offset debits (assuming a 6% discount rate, scaled compensation may range from 360 to 730 poles). Importantly, even with actual data, the scaled amount of compensation is an approximation and only as reliable as the data underlying it.

If the restoration project is delayed -- i.e., project benefits realized further into the future -- then the per unit credit declines, which means even more compensation is required to offset debits. Thus, discounting provides an incentive for those causing environmental damage to provide timely compensation.[20] Note also that long-lasting restoration projects (100 years of gain versus 25 years) result in larger per unit credits and therefore less compensation. Thus, it is in the interest of those who cause environmental damage to ensure long-lasting restoration projects.

Restoration costs & lost environmental value. The costs associated with retrofitting may include (1) the cost of assessment (data collection and equivalency analysis report) and (2) the cost of restoration (materials and labor, future monitoring and reporting, etc). The following question arises: Should total project costs be net of possible cost savings to utilities due to fewer bird-related power outages? I make the assumption that utilities voluntarily invest in some amount of mitigation until the marginal cost equals the marginal benefit they receive (fewer costly outages). The fact that the Bern Convention has requested further investment implies that society

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[20] As reiterated in the conclusion, the primary objective is to avoid and minimize damage; compensation is the third option.

prefers less bird mortality than what utilities consider to be economically optimal. Thus, I assume that the cost to society of the restoration project gains is the additional expenditures requested by the Bern Convention, over and above what the utilities would have invested independently. Thus, the cost of compensation credits to wind power developers depends on the current and projected level of retrofitting investment in a given area.

To estimate costs for the project, I reviewed the literature and contacted utilities, but information was sparse (and inherently site-specific). BirdLife International Hungary estimates 2,400 Euro (20,500 NOK) per km of 20 kV wire insulated and 48,000 Euro (412,000 NOK) per km of underground cabling [55]. Austria estimates 70,000 Euro per km of 20 kV wire underground cabling [62].

These figures provide an indication of the costs that Statkraft might face if they pursue compensation credits based on power line retrofitting. The final cost of a restoration project undertaken by Statkraft may provide some information about the value society places on the loss of sea eagles, even though it is not a fully-appropriate welfare measure of value. For example, economists note that the value of environmental damage should be based on society's willingness to pay to avoid a portion[21] of the external costs of wind power production (e.g., impacts that are not captured by the price of electricity) rather than the cost of replacing damaged resources.[22] The EU project ExternE (www.externe.info) identifies -- and in part monetizes -- the external costs of wind power in a way that accounts for an individual's utility change, thus providing a robust measure of value (the drawback to the economic valuation approach in ExternE is that some of the external costs are difficult to monetize). Despite the fact that the "replacement cost" approach used in equivalency analysis is not an ideal measure of value [63-66], it does provide a starting point to discuss the monetary loss of resources from wind power development. In other words, the fact that similar restoration projects have been implemented in the US (and are required for certain environmental damage in the EU)

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[21] Economist do not suggest that the value is based on the WTP to avoid all external costs; instead, there exists some "optimal" amount of externality, i.e., society may be willing to pay the cost to prevent 95% of bird kills from turbines, but the last 5% may be too expensive.

[22] Intuitively, the cost of replacing a lost item may or may not have anything to do with its inherent value.

provides some evidence that the public[23] is at least willing to pay the cost to support such projects (an indicator of value); it does not, however, tell us whether they may be willing to pay more (or less) to avoid such damage from occurring in the first place, which is the more appropriate measure of value.

1.2.5 Step Five: Monitoring and Reporting

The purpose of monitoring and reporting is monitor project success. For example, a “restoration and compensation” plan may include the following: a protocol for monitoring key criteria (e.g., bird population), a list of goals for restoration success, annual monitoring reports, and suggested revisions to restoration plans as necessary (i.e., mid-course adjustments to ensure the restoration gains promised to the public are actually realized or to prevent gratuitous restoration).

1.3 Conclusion

No power source is devoid of environmental impacts: fossil fuel and coal release CO_2 into the atmosphere, hydropower disrupts the water cycle and fish migration, and wind power has impacts on species and their habitats. A sound environmental policy approach is one that relies on the "Alternative-Mitigation-Compensation" hierarchy to determine whether to proceed with a specific energy project. When applied appropriately within this hierarchy, compensatory measures -- either as required under specific statues or as a voluntary action by power companies -- provide a sensible means of reducing the loss of environmental resources and/or services. But an obvious question arises: how much compensation is required?

This paper presented a framework for determining how much compensation is enough to offset environmental impacts of a wind power project. The framework ensures that the public is not undercompensated for environmental losses and that companies are not required to provide gratuitous restoration. The case study illustrated how one might apply the framework, rather than argue for any specific compensation actions at the Smøla wind farm. The framework requires significant data collection both pre and post wind

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[23] Because Statkraft is "owned" by the public, its actions may proxy public willingness to pay.

farm construction to accurately quantify debits and credit, and hence scale compensation appropriately. Finally, while the framework focused on impacts to a raptor species from turbine collision, it is adaptable to other impacts (e.g., non-raptor species, marine species, habitat fragmentation, etc).

There are two potential criticisms of this approach: the first addresses the concept of compensation within the EIA hierarchy and the second addresses the specific restoration project proposed in this study (i.e., electrocution prevention). I address both of these below.

The first criticism addresses **the use of compensation as a policy mechanism**. The last component of the 'Avoid-Mitigate-Compensate' hierarchy is rarely put into practice. One of the primary reasons for this is the lack of consensus on "how much is enough avoidance/mitigation" before proceeding with compensation [72]. Indeed, before one can answer the question posed in the title of this paper, a clear policy must spell out when a particular project falls into the "compensation realm." Importantly, compensation should never be used to justify an unwise project [71]. The intent of the hierarchy is to avoid conflict areas by having a necessary and critical dialogue with experts on the potential for conflict in certain areas. An example in Sweden where compensation is arguably not the best approach may be the proposed wind farm at Forsmark [67]. The project proposes 15 turbines around a lake (biotestsjön) that receives heavy visitation from raptor species due to the fact that the water remains ice-free for much of the winter. Birds that fly from, or toward, the lake run the risk of turbine collision, although a preliminary study concluded that such risks were hard to predict [68]. A detailed review of this particular project is beyond the scope of this study, however, if such impacts are likely they should be avoided and/or mitigated as part of the EIA process, rather than compensated for ex post (or ex ante). Compensation is best applied ex post when post-project monitoring identifies more severe environmental impacts than originally anticipated. Such impacts are ripe for compensatory measures.

The second criticism focuses on **the selection of electrocution prevention (retrofitting) as a restoration project** in this case, and the selection of restoration projects in general. Selection of a project should be based on a list of limiting factors for a population (or habitat), as in Table I-1 (or see Table II-1 from Paper II). Selection of a final restoration project should consider several criteria including cost, likelihood of success, time delay in producing environmental gains, geographical linkage between damaged and repaired resource/service, etc. (see Section 3.1.2 in [7]).

This paper selected power line retrofitting for illustration purposes, but also argued that it meets several of the key criteria for selecting a restoration project. First, the opportunities for developing compensation credits from electrocution prevention may be extensive -- the literature suggests that electrocution mitigation measures are technically feasible -- indicating a potentially cost-effective mechanism for generating BYs to offset wind power losses. Though not estimated in this paper, anecdotal evidence seems to suggest that total losses from raptor electrocution worldwide is significant relative to wind power,[24] indicating a potentially large 'pool' of available BY credits. Further, this would leverage the scientific advances in the field of electrocution prevention research -- an area in which despite available technological solutions, very little progress has been made. However, some have questioned whether a "credit" occurs if one firm's environmental damage (e.g., a utility causing electrocution mortality) is addressed by a second firm in order to compensate for that firm's environmental damage (e.g., wind turbine mortality).[25] For example some have asked whether this project is reasonable given that the situation could logically be reversed, i.e., the utility could compensate for its electrocution losses by addressing turbine mortality; or, is it fair that the wind power company pays for electrocution prevention measures rather than the utility company?

The first question is valid in the sense that credits should be measured against a baseline scenario, i.e., the situation *without* the restoration project. In this case it may appear that the utilities are (or should be) addressing the problem without the wind power's restoration project. But as noted above, this is not the case. Utility companies do invest in some electrocution prevention to avoid losses associated with costly power outages, but this is not enough from society's point of view. That is, society appears to value the loss of these eagles higher than the utility companies themselves (hence the Bern Convention), who consider only the difference between the "private costs and benefits" of doing something about it. Thus, prevention measures are only being undertaken to a limited extent in the baseline, despite efforts of the Bern Convention (among others) to

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[24] Admittedly, this relationship may change as wind power expands in the future.

[25] Note that this criticism is applicable to at least one other proposed restoration project in Table 1: collisions caused by a train company.

force power companies to insulate more power lines. Thus, from an "additionality" perspective, one could argue that by awarding compensation credits to wind power companies, society will obtain a credit that would not otherwise be realized.

The second question relates to who should pay for the measure, with a suggestion that the polluter (the utility) pay for the electrocution prevention measures based on consideration of fairness (the PPP). For example, hydropower companies compensate for losses to anadromous fish and are not able to pass this cost on to another firm seeking compensation credits. However, a companion to the PPP is the VPP, the Victim Pays Principle, which leads to the same outcome though a different means. The VPP might be appropriate when the polluter is unable (or unwilling) to prevent pollution, while the victim has the ability and incentive to address the problem. A common example is transboundary pollution, where the victim may be a "richer" country that addresses the pollution problem in the "poorer" country. An agreement is reached because the outcome is beneficial to both countries. The VPP may be applicable in our case because utility companies may not have the resources to address the magnitude of the electrocution problem, but the victim (in this case "society" represented by a wind power company) would benefit from an agreement that would protect additional eagles. Of course, such an agreement faces an "incentive compatibility" problem in the sense that the utility company does not have an incentive to truthfully reveal its ability to pay, which may lead to inefficient outcomes (i.e., society -- the victim -- may receive less than the optimal amount of sea eagle protection).

In short, I argue that electrocution prevention measures can produce cost-effective and off-setting environmental gains, despite some valid criticism of the implicit assumptions behind it. The alternative is to consider whether BYs could be cost-effectively produced -- with a relatively high probability of success and with minimal time delay -- through another restoration project (identified from Table I-1, Table II-1 or elsewhere).

Further, it is important to note some general limitations of compensatory restoration scaled using equivalency analysis. For example, even if compensation is a reasonable policy for a given project, there may be technical limits to the capacity of restoration ecology to restore and/or rehabilitate original ecological systems. In other cases, the success of compensatory restoration may be limited by economics, i.e., the cost of compensation for certain habitats or species may be prohibitively expensive. Finally, even when restoration at a particular site can efficiently "create more birds" to compensate for those lost, such approaches should not be independently applied at repeated wind power sites because it may preclude a full understanding of the cumulative impacts of human-caused mortality on birds. Providing sufficient "credit" through independent restoration projects for multiple wind developments will not only be technically and/or economically difficult but may, in fact, be poor environmental policy. From a societal point of view it may be optimal to pursue alternative policies (i.e., do not build the wind farm, build it elsewhere, etc). These types of decisions should be made within a comprehensive and regional wind power planning process rather an individual EIA.

Finally, a key assumption in this study is that the sea eagle population acts as a proxy for the level of environmental damage occurring at the Smøla wind farm. There is good reason to believe the sea eagle is a good indicator species for measuring ecosystem quality [49]. However, environmental damage other than sea eagle collisions are likely to have occurred due to the wind farm but are not captured in this analysis. This may not be a significant problem because the sea eagle proxy for environmental quality implies that measuring its decline and its gain through restoration will ensure reasonable compensation to the public for resource injury. As stated in the REMEDE Toolkit: "If all the damage done is quantified and added independently, the amount of [restoration] indicated might overstate the true amount needed, since a single [restoration] project might address multiple resource damages" (see [7] Part II, Section 2.1.4).

References

[1] Bright, J.A. et al. 2006. *Bird Sensitivity Map to provide locational guidance for onshore wind farms in Scotland*. Available at: http://www.rspb.org.uk/Images/sensitivitymapreport_tcm9-157990.pdf [Accessed August 2, 2009].

[2] Langston, RHW, and J.D. Pullan. 2003. *Windfarms and birds: an analysis of the effects of wind farms on birds, and guidance on environmental criteria and site selection issues*. By BirdLife International to the Council of Europe, Bern Convention. RSPB/Birdlife in the UK. Available at: www.birdlife.org/eu/pdfs/BirdLife_Bern_windfarms.pdf [Accessed July 23, 2009].

[3] California Energy Commission and California Department of Fish and Game. 2007. *California Guidelines For Reducing Impacts To Birds And Bats From Wind Energy Development*. California Energy Commission, Energy Facilities Siting Division and California Department of Fish and Game, Resources Management and Policy Division. Available at: http://www.energy.ca.gov/windguidelines/index.html [Accessed September 15, 2009].

[4] Kreiser, Konstantin, 2005. Position Statement on Wind Farms and Birds: Adopted by the BirdLife Birds and Habitats Directive Task Force on 9 December 2005. Available at: http://www.birdlife.org/eu/pdfs/Nature_Directives_material/BHDTF_Position_Wind_farms_and_birds_2005_12_09.pdf [Accessed September 15, 2009].

[5] Banverket, (Swedish Rail Administration). 2006. *Botniabanan. Kompensation avseende rastande fåglar i slättlandskapet vid Umeälvens delta och slätter (Compensation measures for birds using the SPA located in the outlet areas of River Umeälven as a stop-over site)*.

[6] Smallwood, K.S. “Mitigation in U.S. Wind Farms.” In *Birds of Prey and Wind Farms. Documentation of an International Workshop in Berlin, 21st and 22nd October 2008 (Ed. H. Hötker(*, Available at:

http://bergenhusen.nabu.de/forschung/greifvoegel/ [Accessed July 26, 2009].

[7] Lipton, Joshua et al. 2008. "REMEDE Toolkit for Performing Resource Equivalency Analysis to Assess and Scale Environmental Damage in the European Union" Available at: http://www.envliability.eu/docs/D13MainToolkit_and_Annexes/D13MainToolkit.html.

[8] Statkraft (Norwegian National Power Company). 2006. "Smøla wind farm (project factsheet in .pdf from Statkraft website)." Available at: http://www.statkraft.com/pub/wind_power/windfarms/Smøla/index.asp [Accessed September 4, 2009].

[9] Statkraft Press Release. 2006. "Operational and Research Status at Smøla Wind Farm." Available at: http://www.statkraft.com/pub/wind_power/feature_articles/operational_and_research_status_at_Smøla_wind-farm.asp [Accessed July 14, 2009].

[10] Bevanger, Kjetil, Stig Clausen, and et al. 2008. *Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway*. Norwegian Institute for Nature Research. Available at: www.nina.no/archive/nina/PppBasePdf/rapport/2008/409.pdf [Accessed July 15, 2009].

[11] Bevanger, Kjetil, Arne Follestad, and et al. 2008. *Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway*. Norwegian Institute for Nature Research. Available at: www.nina.no/archive/nina/PppBasePdf/rapport/2008/355.pdf [Accessed July 15, 2009].

[12] Dahl, Espen Lie. 2009b. "PhD student, Norway Institute for Nature Research (NINA)."

[13] Erickson, W. et al. 2001. *Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of collision mortality in the United States*. Available at: www.nationalwind.org/publications/wildlife/avian_collisions.pdf [Accessed July 27, 2009].

[14] de Lucas, M et al. 2008. "Collision fatality of raptors in wind farms does not depend on raptor abundance." *JOURNAL OF APPLIED ECOLOGY* 45(6):1695-1703. Available at: http://apps.isiknowledge.com/full_record.do?product=WOS&search_mode=GeneralSearch&qid=1&SID=Z1EnI5IM2LpB2BE5MHh&page=1&doc=1 [Accessed July 20, 2009].

[15] Färnström, Göran. 2008. "Naturskyddsföreningen protesterar inte mot vindkraftverk." *Vermlands Tidningen*. Available at: http://www.nwt.se/vasterdalarna/article50736.ece [Accessed July 26, 2009].

[16] Liderfelt, David. 2006. “Uppvind för Vindkraften: Motvind för fåglarna? (Downwind for wind power: Headwind for the birds?).” *Calidris (Ölands Ornitologiska Förening)* 4:10-16. Available at: www.oof.nu/html/calidris4-06.pdf [Accessed July 26, 2009].

[17] Ahlen, Ingmar. 2008. “Vindkraft - ett hot för fåglar och fladdermöss? (Wind power - a threat for birds and bats?).” *Biodiverse* 13(1):10-11. Available at: http://biodiverse.wordpress.com/2009/04/27/vindkraft-%E2%80%93-ett-hot-for-faglar-och-fladdermoss/ [Accessed July 20, 2009].

[18] Krone, et al. 2000. “Causes of mortality in white-tailed sea eagles from Germany.” *Sea Eagle 2000 Conference Proceedings*:211-218.

[19] Bevanger, Kjetil. *Birds and wind turbines - BirdWind*. 2008. Norwegian Institute for Nature Research. Available at: http://www.sintef.no/Projectweb/CEDREN/Birdwind/ [Accessed September 9, 2009].

[20] Sveriges lantbruksuniversitet (SLU). 2008. *PlusMinus - A research programme for better analysis in environmental decision-making, sponsered by the Swedish Environment Protection Agency and administered by the department of Forest Economics of the Swedish University of Agricultural Sciences* . Available at: http;//plusminus.slu.se.

[21] Evans, Richards. 2009. “Royal Society for the Protection of Birds Sites Policy Officer, Scotland.”

[22] Ecology and Environment Inc. 2007. *Montezuma Wind Project Final Environmental Impact Report*. Available at: http://www.montezumawind.ene.com/final.aspx [Accessed September 4, 2009].

[23] California Department of Fish and Game, California State Lands Commission, and US Fish and Wildlife Service. 2007. *Stuyvesant/Humboldt Coast Oil Spill: Final Damage Assessment and Restoration Plan/Environmental Assessment*. Available at: http://www.dfg.ca.gov/ospr/spill/nrda/nrda_stuy.html [Accessed July 26, 2009].

[24] California Department of Fish and Game et al. 2006. *S.S. Jacob Luckenbach and Associated Mystery Oil Spills: Final Damage Assessment and Restoration Plan/Environmental Assessment*. Available at: www.dfg.ca.gov/ospr/spill/nrda/luckenbach_final_darp.pdf [Accessed July 26, 2009].

[25] Byrd, Heath et al. 2002. *Estimate of the total injury to diamondback terrapins from the chalk point oil spill*. NOAA’s Damage Assessment, Remediation, and Restoration Program (DARRP), . Available at: http://www.darrp.noaa.gov/northeast/chalk_point/pdf/cpar2038.pdf [Accessed July 28, 2009].

[26] Industrial Economics, Inc. 2004. “Final Lake Apopka Natural Resource Damage Assessment and Restoration Plan.” Available at:

www.sjrwmd.com/lakeapopka/pdfs/DARP.pdf .

[27] Sperduto, M. B, S. P Powers, and M. Donlan. 2003. “Scaling restoration to achieve quantitative enhancement of loon, seaduck, and other seabird populations.” *Marine Ecology Progress Series* 264:221–232.

[28] Peacock, Bruce. 2007. Habitat Equivalency Analysis of the Kilo Wharf Extension Project in Apra Harbor, Guam (Prepared as part of Final Environmental Impact Statement (FEIS), Kilo Wharf Extension, Milcon P-502, Apra Harbor Naval Complex, Guam, Mariana Islands (CEQ # 20070434).

[29] Norwegian Ministry of the Environment. 2002. *Norwegian Biodiversity policy and action plan - cross-sectoral responsibilities and coordination*. Available at: http://www.cbd.int/countries/?country=no [Accessed July 27, 2009].

[30] Norwegian Ministry for the Environment (MoE). 2009. *4th Norwegian National Report to the Convention on Biological Diversity (CBD)*. Available at: http://www.cbd.int/countries/?country=no [Accessed July 28, 2009].

[31] Naturskyddsföreningen. 2009. “Grön Guide (Bra Miljöval - Bra Miljöval el).” *El från sol, vind och vatten*. Available at: http://www.naturskyddsforeningen.se/gron-guide/bra-miljoval/el-markt-med-bra-miljoval/ [Accessed July 26, 2009].

[32] Ozdemiroglu, Ece et al. 2009. “Environmental Liability Directive and the use of economics in compensation, offsets and habitat banking.” In *UK Network for Environmental Economists* , London, England. Available at: http://www.eftec.co.uk/UKNEE/envecon/2009_documents/2009_agenda.htm [Accessed August 9, 2009].

[33] Cole, Scott, and Bengt Kriström. 2008. “Annex 5: Discounting.” In *REMEDE Toolkit for Performing Resource Equivalency Analysis to Assess and Scale Environmental Damage in the European Union* , Produced by the REMEDE Team (www.envliability.eu) for the European Commission. Available at: http://www.envliability.eu/docs/D13MainToolkit_and_Annexes/D13MainToolkit.html.

[34] Morris, R.K.A. et al. 2006. “The creation of compensatory habitat--Can it secure sustainable development?.” *Journal for Nature Conservation* 14(2):106-116. Available at: http://www.sciencedirect.com/science/article/B7GJ6-4JF8HH2-1/2/a0e4f1a969727cbddc81a801316df61e [Accessed March 17, 2009].

[35] Hilderbrand, RH, AC Watts, and AM Randle. 2005. “the myths of restoration ecology.” *Ecology and Society* 10(1):19. Available http://www.ecologyandsociety.org/vol10/iss1/art19/ES-2005-1277.pdf [Accessed March 16, 2009].

[36] Burfield. Ian J. 2009. “The Conservation Status and Trends of Raptors and Owls in Europe.” Available at: http://www.bioone.org/doi/full/10.1579/0044-

7447%282008%2937%5B401%3ATCSATO%5D2.0.CO%3B2 [Accessed July 14, 2009].

[37] Nordic Council of ministers. 2008. *The Triumphant return of the white-tailed eagle*. Available at: www.environment.fi/nordicnature --> fact sheets --> The triumphant return of the white-tailed eagle [Accessed July 19, 2009].

[38] Hailer, Frank, and et al. 2006. "Bottlenecked but long-lived: high genetic diversity retained in white-tailed eagles upon recovery from population decline." *Biology Letters* 2:316-319. Available at: http://rsbl.royalsocietypublishing.org/content/2/2/316 [Accessed July 15, 2009].

[39] Stjernberg, T., and J. Koisvusaari. 1995. " The recovery of the white-tailed sea eagle in Finland in 1970 – 1994." *Linnut* 30:5-14

[40] Hauge, Kjell-Ove. 2003. "Havorna i Rogaland: Historisk tilbakeblikk og status for hekkebestanden fram til og med 2003 (The white-tailed eagle in county of Rogaland: historical review and data on the present breeding population)." *Stavanger Museum Arbok* (113):73-83.

[41] BirdLife International. *Haliaeetus albicilla. In: IUCN 2009. IUCN Red LIst of Threatened Species.* . Available at: www.iucnredlist.org [Accessed July 26, 2009].

[42] BirdLife International. 2009. *Species factsheet: Haliaeetus albicilla*. Available at: http://www.birdlife.org/datazone/species/index.html?action=SpcHTMDetails.asp&sid=3364&m=0 [Accessed July 19, 2009].

[43] Helander, B., and T. Stjernberg. 2003. *2003 Species Action Plan for the Conservation of White-tailed Eagle*. Birdlife International, Convention on the Conservation of European Wildlife and Natural Habitats. Available at: http://www.coe.int/t/dg4/cultureheritage/conventions/bern/T-PVS/sc22_inf02rev_en.pdf [Accessed July 14, 2009].

[44] Norwegian Orinithological Society, (NOF), and (RSPB) Royal Society for the Protection of Birds. 2008. "Possible New File: Windfarm in Smøla Archipelago (Norway)." Available at: http://www.coe.int/t/dg4/cultureheritage/Conventions/Bern/T-PVS/sc26_files11_en.pdf [Accessed June 9, 2009].

[45] Helander, Björn. 2009. *Åtgärdsprogram för havsörn 2009 - 2013*. Naturvårdsverket (Swedish Environmental Protection Agency). Available at: http://www.naturvardsverket.se/sv/Nedre-meny/Webbokhandeln/ISBN/5900/978-91-620-5938-5/ [Accessed July 20, 2009].

[46] Helander et al. 2009. "Ingestion of lead from ammunition and lead concentrations in white-tailed sea eagles

[47] Norway Directorate of Natura Management. 2001. "Letter from Norway's Directorate of Nature Management (Ola Skauge) to the Bern Convention (Eladio Fernandez-Galiano) regarding "Wind farm planning at Smøla Island"."

[48] Bevanger, Kjetil, and Kristian Overskaug. 1998. "Utility Structures as mortality factor for Raptors and Owls in Norway." In *Holarctic Birds of Prey, Edited by Chancellor, R.D., B. U. Meyburg, and J.J. Ferrero*,

[49] Helander, Björn, Anders Bignert, and Lillemor Asplund. 2008. "Using raptors as environmental sentinels: monitoring the white-tailed sea eagle Haliaeetus albicilla in Sweden." *Ambio* 37(6):425-431. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18833795 [Accessed July 14, 2009].

[50] Evans, Richard J. et al. 2009. "Growth and demography of a re-introduced population of White-tailed Eagles <i>Haliaeetus albicilla</i>." *Ibis* 151(2):244-254. Available at: http://dx.doi.org/10.1111/j.1474-919X.2009.00908.x [Accessed July 27, 2009].

[51] Norwegian Government Agency for Financial Management (SSØ) . 2005. *Veileder i samfunnsøkonomiske analyser (Guidelines for socioeconomic analyses)*. Available at: http://www.regjeringen.no/upload/kilde/fin/reg/2005/0029/ddd/pdfv/266324-veileder_i_samfunnsok_analyse_trykket.pdf [Accessed June 10, 209].

[52] Navrud, Ståle. 2009. "Associate Professor in Environmental and Resource Economics, Department of Economics and Resource Management, Norwegian University of Life Sciences."

[53] Bevanger, Kjetil. 1994. "Bird interactions with utility structures: collision and electrocution, causes and mitigating measures." *Ibis* 136(4):412-425. Available at: http://dx.doi.org/10.1111/j.1474-919X.1994.tb01116.x [Accessed July 17, 2009].

[54] Birkö, Thomas. 2002. "Eldöden bland fåglar ännu stort problem." *Vår Fågelvärld* 6:22-23.

[55] Horvath, Marton. 2009. "PhD Student in orinthology, BirdLife International, Hungary (MME)."

[56] Lowen, James. 2008. "Price of Power." *World Bird Watch*. Available at: http://www.birdlife.org/news/features/2008/03/power_lines.html [Accessed August 31, 2009].

[57] Haas, D et al. *Protecting Birds from Powerlines: a practical guide on the risks to birds from electricity transmission facilities and how to minimise any such adverse effects*. Available at: http://www.coe.int/ [Accessed September 1, 2009].

[58] Bevanger, Kjetil, and et al. 2008. "Optimal design and routing of power lines: ecological, technical and economic perspectives OPITPOL (A project proposal to the Norwegian Research Council, 4 June 2008)." Available at:

http://www.sintef.no/project/CEDREN/OPTIPOL_Final.pdf [Accessed July 15, 2009].

[59] Bern Convention. 2004. *Recommendation No. 110 (2004) on minimising adverse effects of above-ground electricity transmission facilities (power lines) on birds*. Bern Convention on the Conservation of Europena Wildlife and Natural Habitats. Available at: http://www.coe.int/t/dg4/cultureheritage/conventions/Bern/Recommendations/ListRec_en.asp [Accessed September 5, 2009]

[60] Lehman, Robert N., Patricia L. Kennedy, and Julie A. Savidge. 2007. “The state of the art in raptor electrocution research: A global review.” *Biological Conservation* 136(2):159-174. Available at: http://www.sciencedirect.com/science/article/B6V5X-4MNYJY8-1/2/edd3f01d55d066dfed77b3973903faf7 [Accessed September 16, 2009].

[61] Allander, Klas (Swedish EPA). “Report on the implementation of Bern Convention Recommendation 110 (2004) on minimizing adverse effects of power lines on birds - SWEDEN (Letter from the Swedish EPA to the Council of Europe, Bern Convention, August 12, 2009.”

[62] Raab, Rainer. 2009. “Interview with Technisches Büro für Biologie, LIFE Nature Project, www.grosstrappe.at.”

[63] Riera, Pere. 2008. “Does the equivalency analysis of the European Environmental Liability Directive pass a social cost-benefit analysis test?.” *Journal of Forest Economics* 14(4):225-226. Available at: http://www.sciencedirect.com/science/article/B7GJ5-4TWSWVT-1/2/5cee8957bea5969b65f29dba31f125aa [Accessed September 16, 2009].

[64] Unsworth, R. E., and R. C. Bishop. 1994. “Assessing natural resource damages using environmental annuities.” *Ecological Economics* 11(1):35-41.

[65] Weiss, J.C., B.B. Boehler, and R. E. Unsworth. 2007. *Assessing the costs and benefits of electricity generation using alternative energy resources on the Outer Continental Shelf. Prepared for U.S. Dept of the Interior, Minerals Management Service*. OCS Study MMS 2007-013. Herndon, VA: USDOI/MMS, Offshore Environmental Division. Available at: http://ocsenergy.anl.gov/documents/docs/final_synthesis_report.pdf [Accessed September 15, 2009].

[66] Unsworth, R. E. 2005. Appendix E "Economic Costs of Once-Through Cooling Impacts by Robert Unsworth Industrial Economics" found in "Issues and environmental impacts associated with once-through cooling at California’s coastal power plants". Produced for the California Energy Commission. Available at: http://www.energy.ca.gov/siting/once_through_cooling.html [Accessed September 15, 2009].

[67] Nevelius, Eva. 2010. Vattenfalls örnstudie får underkänt [Eagle impact study by hydropower company "Vattenfall" fails]. Uppsalas Nya Tidning. 16 January 2010.

[68] Pettersson, Jan and Alf Sevastik. 2009. En havörnsstudie vid Forsmark och Biotestsjön [A sea eagle study at Forsmarm and Biotest Lake]. Prepared for Vattenfall Vindkraft AB. Farjestaden och Osthammar. February 17.

[69] Helander, B. 2003. The international colour ringing programme – adult survival, homing and the expansion of
the white-tailed sea eagle in Sweden. In: SEA EAGLE 2000. Helander, B., Marquiss, M. and Bowerman, B. (eds). Åtta.45 Tryckeri AB, Stockholm, pp. 145-154.

[70] Nygård, T., R. E. Kenward, and K. Einvik. Radio-telemetry studies of dispersal and survival in juvenile white-tailed sea eagles Haliaeetus albicilla in Norway. Proc Conf Raptors at Risk 2000. 487–497.

[71] Norton, D. (2008). Biodiversity Offsets: Two New Zealand Case Studies and an Assessment Framework. Environmental Management [online], 43(4), 698-706. Available from: http://dx.doi.org/10.1007/s00267-008-9192-5. [Accessed 2009-03-16].

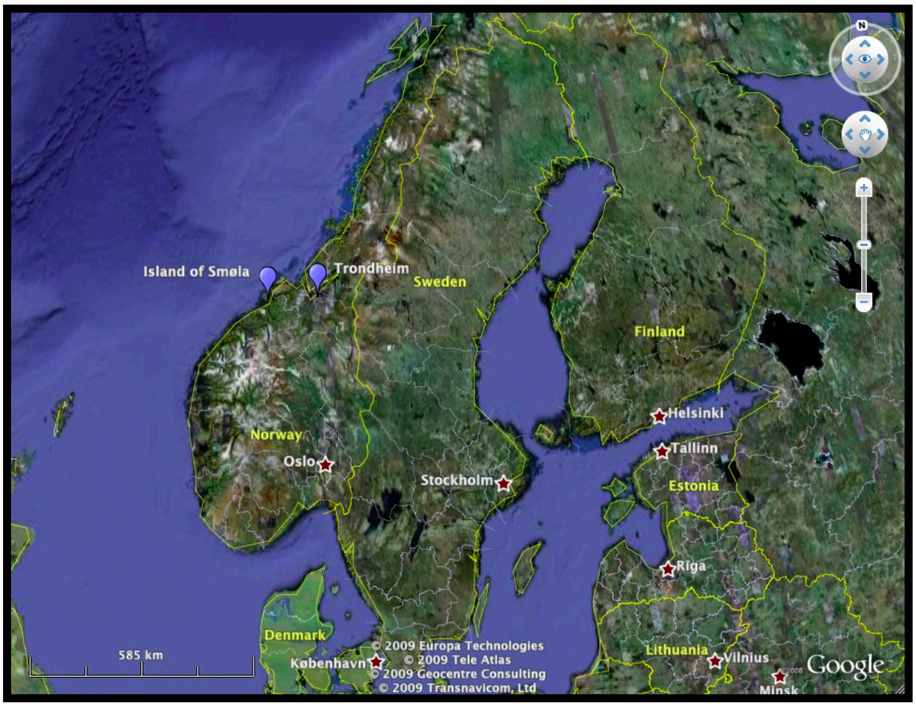
[72] Davis, Adam. 2009. Scenarios for Compensatory Mitigation for Impacts from Wind Energy Development presented at the Compensatory Mitigation Webinar Series, National Wind Collaborating Committee, September 15.

[73] Folkstad A.O. 2003 Status of the white-tailed sea eagle in Norway. In Sea eagle 2000 (ed. B. Helander, M. Marquiss & W. Bowerman). Proc. Int. Conf. Björkö, Sweden, 13-17 September 2000, pp. 51-55. Stockholm: Swedish Society for Nature Conservation/SNF & Åtta.45 Tryckeri AB.

Appendices

Appendix A	*Overview map of Smøla*
Appendix B	*Calculation of average age of the sea eagle population at Smøla (used in debit calculation and credit calculations)* *(determines the starting age for debit and credit calculations -- see "Age" column in both Appendix C and E)*
Appendix C	*Calculation of discounted life expectancy of an average-aged bird* *(used in Tables I-3 and I-4 to estimate debit and credit)*
Appendix D	*Calculation of discounted life expectancy at birth* *(Used as input to calculation of "production potential per average-aged sea eagle" -- see Column E of Appendix E)*
Appendix E	*Calculation of production per average-aged sea eagle* *(used in Table I-3 Column F and Table I-4 Column F)*

Appendix A: Overview map of Smøla



Appendix B: Average age of the sea eagle population at Smøla (determines starting age for debit and credit calculations -- column B in App C & E)

Age	Annual Survival Rate	Probability of surviving to a given age	Probability that randomly chosen bird is this age	Average Age (weighted by probability)
A	B	C	D	E
	(Table I- 2)	$C=C_{age-1}* B_{age}$	D=C/(Sum of C)	E=A*D
1	0.8200	0.8200	0.0665	0.0665
2	0.8200	0.6724	0.0545	0.1090
3	0.8600	0.5783	0.0469	0.1406
4	0.9500	0.5494	0.0445	0.1781
5	0.9700	0.5329	0.0432	0.2160
6	0.9700	0.5169	0.0419	0.2514
7	0.9700	0.5014	0.0406	0.2845
8	0.9700	0.4863	0.0394	0.3154
9	0.9700	0.4717	0.0382	0.3442
10	0.9700	0.4576	0.0371	0.3709
11	0.9700	0.4439	0.0360	0.3958
12	0.9700	0.4306	0.0349	0.4188
13	0.9700	0.4176	0.0339	0.4401
14	0.9700	0.4051	0.0328	0.4597
15	0.9700	0.3930	0.0319	0.4778
16	0.9700	0.3812	0.0309	0.4943
17	0.9700	0.3697	0.0300	0.5095
18	0.9700	0.3586	0.0291	0.5233
19	0.9700	0.3479	0.0282	0.5358
20	0.9700	0.3374	0.0274	0.5471
21	0.9700	0.3273	0.0265	0.5572
22	0.9700	0.3175	0.0257	0.5662
23	0.9700	0.3080	0.0250	0.5742
24	0.9700	0.2987	0.0242	0.5812
25	0.9700	0.2898	0.0235	0.5872
26	0.9700	0.2811	0.0228	0.5924
27	0.9700	0.2726	0.0221	0.5967
28	0.9700	0.2645	0.0214	0.6003
29	0.9700	0.2565	0.0208	0.6030

30	0.9700	0.2488	0.0202	0.6051
		12.34	1.00	**12.94**

Example calculation - Appendix B: Column A indicates the life expectancy of a sea eagle (30 years) and Column B indicates the estimated annual survival rate at each age (see Table I-2 in this paper). Column C estimates the probability of a bird surviving to a given age. For example, for a bird of age 3 this is the probability of surviving to the previous age, age=2, which is 0.6724 times the probability of surviving to the next year, age=3, which is .8600. This product is equal to .5783 as shown (note that the probability of surviving to age 1 is simply the annual survival rate for a one-year old, which is .8200). The probability that a randomly chosen bird is of a given age (Column D) is simply the probability of a bird surviving to that age (.5783 in our example where age=3) divided by the sum of the probabilities of surviving to a given age (12.34). This is .0469 as shown. To determine the average age of the sea eagle population we determine the average age of a bird at each age class -- weighted by its probability of reaching that age (Column E) -- and then sum across a full life span of 30 years. This gives 12.94. In the calculations that follow we round this to 13 years of age.

Appendix C: Discounted life expectancy of an average-aged bird (used in Tables I-3 and I-4 to estimate debit and credit)

Year after event[a]	Age	Annual Survival Rate	Probability of surviving to a given age	BYs per bird that survives to this year (nominal)[b]	BYs per bird that dies in this year (nominal)[b]	Discount factor (based on r = 3%)[c]	Discounted Life expectancy of average aged bird
A	B	C	D	E	F	G	H
		(Table I-2)	$D=D_{age-1}* C_{age}$	$E=D_{age}*1$	$F=D_{age-1}*[1-C_{age}]*(1/2)$	formula[c]	H=(E+F)*G
0	13[d]		1.00				
1	14	0.9700	0.9700	0.9700	0.0150	0.9709	0.9563
2	15	0.9700	0.9409	0.9409	0.0146	0.9426	0.9006
3	16	0.9700	0.9127	0.9127	0.0141	0.9151	0.8481
4	17	0.9700	0.8853	0.8853	0.0137	0.8885	0.7987
5	18	0.9700	0.8587	0.8587	0.0133	0.8626	0.7522
6	19	0.9700	0.8330	0.8330	0.0129	0.8375	0.7084
7	20	0.9700	0.8080	0.8080	0.0125	0.8131	0.6671
8	21	0.9700	0.7837	0.7837	0.0121	0.7894	0.6283
9	22	0.9700	0.7602	0.7602	0.0118	0.7664	0.5917
10	23	0.9700	0.7374	0.7374	0.0114	0.7441	0.5572
11	24	0.9700	0.7153	0.7153	0.0111	0.7224	0.5247
12	25	0.9700	0.6938	0.6938	0.0107	0.7014	0.4942
13	26	0.9700	0.6730	0.6730	0.0104	0.6810	0.4654

14	27	0.9700	0.6528	0.6528	0.0101	0.6611	0.4383
15	28	0.9700	0.6333	0.6333	0.0098	0.6419	0.4127
16	29	0.9700	0.6143	0.6143	0.0095	0.6232	0.3887
17	30	0.9700	0.5958	0.5958	0.0092	0.6050	0.3661
Discounted life expectancy of an average-aged bird *(Discounted Birds Years, DBYs)*							**10.50**

[a] Event is defined as either the collision (debit as in Table I-3) or being 'saved' from electrocution (credit as in Table I-4). That is, we assume collided birds and birds avoiding electrocution are of an average age.

[b] We assume the number of nominal BYs contributed by an individual is 1 BY for those surviving through a given year and 1/2 BY for those dying in a given year.

[c] Discounted to year of event (collision or being "saved" from electrocution, i.e., Column A =0). Total impacts in Tables I-3 and I-4 are then discounted back to the base year of the analysis (2009). The formula for discounting is $1/[(1+r)^{\text{current yr - base year}}]$, where we assume r equals three percent

[d] Assumes average age bird of 12.9 years is rounded to 13. Probability of surviving to 13 is 1.0

Example calculation - Appendix C: The goal is to estimate the total BYs contributed by the average-aged bird that collides with a turbine or is saved from electrocution. Thus, the calculation covers the period from age 13 to maximum age 30. Column C is the annual survival rate as given in Table I-2 in the report. Column D estimates the probability of surviving to a given age (see identical calculation example in Column C, Appendix B above). Columns E and F estimate the actual BYs contributed by a bird that survives to, or dies in, a given year and is based on the assumption in footnote b. Thus, the BYs in Column E for a 16 year old bird are equal to the probability of surviving to that year (.9127) times one, which equals .9127. The BYs for a 16 year old bird in Column F are equal to the probability of surviving to the previous year (.9409) times the probability of dying in the subsequent year (1-.9700) times 1/2, which is equal to .0141. Column G is the discount factor that is applied to the 'nominal value' of BYs in Columns E and F to reflect society's positive time preference. The discount factor is based on the formula in the table footnote above and assumes a discount rate r=3%. For example, the discount factor for 1 year after the event is equal to 1/[(1+.04)^(1-0)] = .9709. The final step in Column H is to sum the BYs contributed by a bird that survives to (column E), or dies in (column F) a given year, and multiply them by the discount factor (column G). Then we sum this value in Column H to get the total contribution over the lifetime of an average bird, which is 10.5 Discounted Bird Years.

Appendix D: Discounted life expectancy at birth (Used as input to calculation of "production potential per average-aged sea eagle" -- see Column E of Appendix E)

Year after birth	Age	Annual Survival Rate	Probability of surviving to a given age	BYs per bird that survives to this year (nominal)[a]	BYs per bird that dies in this year (nominal) [a]	Discount factor (based on r = 3%)[b]	Discounted life expectancy at birth
A	B	C	D	E	F	G	H
		(Table I-2)	D=D(age-1)* C(age)	$E=D_{age}*1$	$F=D_{age-1}*[1-C_{age}]*(1/2)$	formula[a]	H=(E+F)*G
1	1	0.8200	0.8200	0.8200	0.0000	1.0000	0.8200
2	2	0.8200	0.6724	0.6724	0.0738	0.9709	0.7245
3	3	0.8600	0.5783	0.5783	0.0471	0.9426	0.5894
4	4	0.9500	0.5494	0.5494	0.0145	0.9151	0.5160
5	5	0.9700	0.5329	0.5329	0.0082	0.8885	0.4808
6	6	0.9700	0.5169	0.5169	0.0080	0.8626	0.4528
7	7	0.9700	0.5014	0.5014	0.0078	0.8375	0.4264
8	8	0.9700	0.4863	0.4863	0.0075	0.8131	0.4016
9	9	0.9700	0.4717	0.4717	0.0073	0.7894	0.3782
10	10	0.9700	0.4576	0.4576	0.0071	0.7664	0.3561
11	11	0.9700	0.4439	0.4439	0.0069	0.7441	0.3354
12	12	0.9700	0.4306	0.4306	0.0067	0.7224	0.3158

13	13	0.9700	0.4176	0.4176	0.0065	0.7014	0.2974
14	14	0.9700	0.4051	0.4051	0.0063	0.6810	0.2801
15	15	0.9700	0.3930	0.3930	0.0061	0.6611	0.2638
16	16	0.9700	0.3812	0.3812	0.0059	0.6419	0.2484
17	17	0.9700	0.3697	0.3697	0.0057	0.6232	0.2340
18	18	0.9700	0.3586	0.3586	0.0055	0.6050	0.2203
19	19	0.9700	0.3479	0.3479	0.0054	0.5874	0.2075
20	20	0.9700	0.3374	0.3374	0.0052	0.5703	0.1954
21	21	0.9700	0.3273	0.3273	0.0051	0.5537	0.1840
22	22	0.9700	0.3175	0.3175	0.0049	0.5375	0.1733
23	23	0.9700	0.3080	0.3080	0.0048	0.5219	0.1632
24	24	0.9700	0.2987	0.2987	0.0046	0.5067	0.1537
25	25	0.9700	0.2898	0.2898	0.0045	0.4919	0.1448
26	26	0.9700	0.2811	0.2811	0.0043	0.4776	0.1363
27	27	0.9700	0.2726	0.2726	0.0042	0.4637	0.1284
28	28	0.9700	0.2645	0.2645	0.0041	0.4502	0.1209
29	29	0.9700	0.2565	0.2565	0.0040	0.4371	0.1139
30	30	0.9700	0.2488	0.2488	0.0038	0.4243	0.1072
Discounted life expectancy at birth for a sea eagle *(Discounted Bird Years, DBYs)*							**9.17**

[a] We assume the number of nominal BYs contributed by an individual is 1 BY for those surviving through a given year and 1/2 BY for those dying in a given year.

[b] Discounted to year of birth (i.e., column A Year =1). Total impacts in Tables I-3 and I-4 are then discounted back to the year of the analysis (2009). The formula for discounting is $1/[(1+r)^{\text{current yr - base year}}]$, where we assume r equals three percent

Example calculation - Appendix D: The goal is to estimate the total Discounted Bird Years (DBYs) contributed by a newly born bird -- either one that is not born due to turbine collision of parent or a bird that is born due to avoided electrocution death of parent. Thus, the calculation covers the full life expectancy from birth to maximum age 30 (column B). The calculations in columns E, F, G, and H are exactly the same as in Appendix C, except that the time period is longer. Note that the discounted life expectancy of a new born (9.17) is less than the discounted life expectancy of an average age bird (10.5) even though the former has 17 extra years to live (30 - 13 = 17). Its discounted life expectancy is less because (1) survival probabilities are less for juveniles (e.g., 82 to 95%) than for adults (97%) and (2) discounting reduces the value of things occurring far into the future, e.g., BYs contributed in a bird's later years -- which has a proportionally larger effect on life expectancy calculated from birth than life expectancy calculated from an average age.

Appendix E: Estimated production per average-aged sea eagle[a] (used in Table I-3 Column F and Table I-4 Column F)

Year after event[b]	Age	Annual survival rate	Probability of surviving to this age	Sea eagle that would have lived to a given age but for event	No of offspring per year (0.46 per pair, Table I-2)[c]	Discounted life expectancy of offspring[d]	Production
		A	B	C	D	E	F
		(Table I-2)	$B=A_{age} * B_{age-1}$	$C= B_{age} * C_{age-1}$	$D=(0.46)*C_{age}$	Appendix D	F=D*E
0	13[e]		1.0	1.0			
1	14	0.9700	0.9700	0.9700	0.4462	9.17	4.0915
2	15	0.9700	0.9409	0.9127	0.4198	9.17	3.8497
3	16	0.9700	0.9127	0.8330	0.3832	9.17	3.5135
4	17	0.9700	0.8853	0.7374	0.3392	9.17	3.1105
5	18	0.9700	0.8587	0.6333	0.2913	9.17	2.6711
6	19	0.9700	0.8330	0.5275	0.2426	9.17	2.2249
7	20	0.9700	0.8080	0.4262	0.1960	9.17	1.7977
8	21	0.9700	0.7837	0.3340	0.1537	9.17	1.4089
9	22	0.9700	0.7602	0.2539	0.1168	9.17	1.0711
10	23	0.9700	0.7374	0.1873	0.0861	9.17	0.7899
11	24	0.9700	0.7153	0.1339	0.0616	9.17	0.5650

12	25	0.9700	0.6938	0.0929	0.0428	9.17	0.3920
13	26	0.9700	0.6730	0.0626	0.0288	9.17	0.2638
14	27	0.9700	0.6528	0.0408	0.0188	9.17	0.1722
15	28	0.9700	0.6333	0.0259	0.0119	9.17	0.1091
16	29	0.9700	0.6143	0.0159	0.0073	9.17	0.0670
17	30	0.9700	0.5958	0.0095	0.0044	9.17	0.0399
Total production per average-aged sea eagle *(Discounted Bird Years, DBYs)*							**26.1**

[a] We calculate production per female sea eagle and assume a male is available in the population to complete the pair.

[b] Assumes average age bird of 12.9 years is rounded to 13. Probability of surviving to 13 is 1.0

[c] Productivity estimate based on [73].

[d] Discounted to year of event (collision or being "saved" from electrocution). Total impacts in Tables I-3 and I-4 are then discounted back to the year of the analysis (2009).

[e] Assumes average age bird of 12.9 years is rounded to 13. Probability of surviving to 13 is 1.0.

Example calculation - Appendix E: The goal is to estimate the indirect Discounted Bird Years (DBYs) associated with production; i.e., *lost* production for a bird that collides or *gained* production for a bird that is saved from electrocution. Thus, the relevant time period is age 13 (average age) until maximum age. Columns A and B are calculated as per Appendices B. Column C represents a given bird that would have reproduced, but fore the event. That is, Appendix E calculates production per (one) eagle. This integer (1) theoretically declines each year because the probability of this (one) eagle surviving to a given age to give birth declines over time. For example, this (one) eagle is available at age 13 to give birth, but the probability of that one eagle being around at age 14 (one year after the event) to give birth is 1 times the probability of surviving to age=14 (.9700 from Column B), which is equal to 0.9700 (Column C). In other words, there is a 3% chance that the (one) eagle is not available in one year to give birth. Similarly, two years later that one eagle is even less likely to be present to give birth, which we calculate by taking the 0.9700 chance of giving birth after one year and multiplying it be the chance of surviving to the next age (.9409 from Column B), which is equal to .9127. Column D represents the number of offspring expected from each female sea eagle (assumed to have found a male). This is equal to the probability that this female is around to give birth (Column C) times the number of offspring expected per pair (0.46). For example, the offspring produced by a 16 year old female (3 years after the event) is equal to the probability that the female is alive

(.8330) times the number of offspring expected (.46). Thus, the offspring per year per pair declines over time due to reduced probability that a parent will have lived to that age to give birth. To determine the contribution of BYs from that offspring, we must know its discounted life expectancy (Column E), which is 9.17 (see Appendix D). Finally, production is equal to the number of offspring (column D) times its life expectancy (column E), which is shown in Column F. We sum this column over the years of the parent to determine the total production from an average aged sea eagle, 26.1 Discounted Bird Years.

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Acknowledgements

This paper -- presented at the Offshore Wind 2009 Conference in Stockholm -- acknowledges support from the Swedish Environmental Protection Agency. The study also considers research conducted by the Norwegian Institute for Nature Research (NINA). The author thanks Kjetil Bevanger and Espen Lie Dahl from NINA for their valuable comments on earlier drafts and Birger Hörnfeldt (Swedish Agricultural University, Department of Wildlife, Fish, and Environmental Studies) for his tedious review of my calculations and various suggestions for improvements in later drafts. The author takes all responsibility for remaining errors.