Appendix 4: ROUGE RIVER 2002 MYSTERY OIL SPILL SIMAP INJURY REPORT: Restoration Scaling Model and Results

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ROUGE RIVER 2002 MYSTERY OIL SPILL
SIMAP INJURY REPORT
Restoration Scaling Model and Results
Draft for Trustee Review

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Bioenergetics Modeling to Rear Fledglings

Habitat Equivalency Analysis (HEA) has been used by state and federal trustees to estimate the restored habitat required to compensate for habitat injured, taking into account the time before the project is begun (lag time after the spill and injuries occur), the time for development of the restored habitat, the ultimate productivity of services in the new habitat as compared to that injured, the duration of the restoration project life, and discounting of future habitat services at 3% per year). The approach and equations are described in NOAA (1997, 1999), LA DEQ et al. (2003), and French-McCay and Rowe (2003).

In a HEA trophic transfer model, a trophic transfer model is used to calculate wildlife production as a function of production of food resources by a restored habitat. This is the simplest approach for scaling restoration, which is typically used for small spills. It follows the same approach as for fish and invertebrates, except it replaces the biomass of the wildlife directly killed with wildlife biomass at an equivalent trophic level. This approach does not address the species one-to-one or the age structure of the animals lost, and so the varying relative value of different age classes of animals lost (i.e., that older animals "cost" more to replace in terms of food and improved survivorship).

An alternative approach (as was used for the EverReach spill) is to calculate a habitat scale requirement based on energetic costs of rearing fledglings. A bioenergetic model was used to calculate food requirements (by parent and chick) to grow a chick to fledging, including a percentage loss due to mortality. Then, the scale of wetland required in compensation was that which would produce the required amount of food (e.g., fish). A similar approach could be used for mammal losses based on equivalents of reared or weaned individuals to the killed animals. However, a species-specific bioenergetic model would require elaborate spreadsheet calculations, and was not feasible within the scope of this project based on data availability.

Instead of developing an incident specific bioenergetic model, a literature search was conducted on bioenergetic models of species typical of those in the area of the spill, and the data provided from those studies on food requirements to rear a fledgling was used as inputs into a trophic HEA model. The needed data include the amount of food required per chick until fledging plus the amount of additional food required by a parent bird over-and-above that required by a non-breeding bird per chick reared. Then, the kilograms of food needed per fledgling was multiplied by fledgling-equivalents killed to get the biomass (kilograms) of food (fish or invertebrate) that need to be restored. The biomass of food to restore (assuming piscivores consume small pelagic fish and invertebrate consumers consume benthic invertebrates) was then input into a trophic HEA model to calculate the area of wetland required to produce the food for the fledgling, with appropriate discounting. The below outlines the calculations, using fish as an example food (i.e., for piscivorous birds):

kg fish needed/fledgling * fledgling-equivalents killed = fish to restore

fish to restore → trophic HEA → marsh needs

The bird species injured include the following groups, categorized by taxonomic groupings and primary food. Bioenergetics data needs for rearing a chick to fledging were developed for at least one representative of each group:

- Dabbling ducks (consume invertebrates)
- Geese (consume invertebrates, vegetation)
- Swans (consume invertebrates, vegetation)
- Diving ducks (consume invertebrates)
- Diving ducks and grebes (consume fish)
- Cormorants (consume fish)
- Gulls (consume fish)
- Terns (consume fish)
- Waders (consume fish)
- Shorebirds (consume invertebrates)

The bioenergetics data developed for each group are summarized in Table 1 below. The total weight of food required per fledging was developed from literature sources using the group representative listed in the table. The food requirements are summed over the development period from hatching to fledging, accounting for higher food requirements of larger chicks. To calculate the food requirements of non-breeding adults, the following equations (from Nagy, 1987) describing food ingestion (FI) rates in grams of dry matter/day as a function of body weight in grams (M) were used:

For seabirds: $FI = 0.495M^{0.704}$

For all other birds: $FI = 0.648M^{0.651}$

To determine the food requirements of breeding adults, a ratio of 2.9 was applied to the food ingestion rates calculated for non-breeders. This ratio is based on data for great blue heron from Bennett et al. (1993), who state that the above provisioning levels (assuming both parents contribute equally to feeding the chicks) represent a 2.6- and 3.2-fold increase in the amount of maintenance energy that the parents must obtain in order to meet the energy needs of themselves and their chicks during the time of peak energy consumption of the chicks. The food ingestion rates for breeding adults were then multiplied by the length of the fledgling period to determine the total amount of extra food required for breeding adults.

The injured mammals include only muskrat. Given that this species is a vegetarian, and is not a species of concern, the simple trophic HEA modeling approach was used. The directly oiled biomass (number times average weight per animal) of muskrat was used for the scaling calculations.

The injured reptiles and amphibians are not species that would provide care to their young. The injury has been calculated three ways: as a direct loss of biomass, hatchling-equivalents lost, and number-years of loss. However, the simple trophic HEA modeling approach, using the directly oiled biomass (number times average weight per animal), was used, as these groups are function in the trophic web most similar to fish. Their metabolic rates and food needs are also most like fish, as they are all poikilotherms (cold-blooded animals).

Table 1. Summary of bioenergetics data developed for bird groups.

Group	Group Representative	Fledgling Losses (Total for Group)[1]	Total Food Required per Fledging (g)[14]	Total Extra Food Required for Breeding Adults (g)[2]	Total Food Required for Replacing Fledgling-Equivalents Lost (kg)[3]
Piscivorous birds					
Waders	Great blue heron	342	23,720[5]	41,704	2,238
Diving ducks and grebes	Great-crested grebe	7,523.8	8,120[6]	20,745	217,173
Cormorants	Double-crested cormorant	941.0	15,188[7]	45,064	56,697
Gulls	Herring gull	1,653.9	7,008[8]	26,625	55,626
Terns	Common tern	162.4	600[9]	3,807	716
Birds feeding on invertebrates/ vegetation[4]					
Shorebirds	Black-tailed godwit	200.1	2,675[10]	0	535
Geese and swans	Greater snow goose	43.1	1,841[11]	0	79
Dabbling ducks	American black duck	585.3	2,793[12]	0	1,635
Diving ducks	Canvasback	7,664.3	7,514[13]	0	57,593

[1] From biological model results.
[2] To calculate the food requirements of non-breeding adults, the following equations (from Nagy, 1987) describing food ingestion (FI) rates in grams of dry matter/day as a function of body weight in grams (M) were used. For seabirds: $FI = 0.495M^{0.704}$. For all other birds: $FI = 0.648M^{0.651}$. To determine the food requirements of breeding adults, a ratio of 2.9 was applied to the food ingestion rates calculated for non-breeders.
[3] Number of fledglings-equivalents lost * (food required per fledgling + extra food required for breeding adults).
[4] It is assumed that for these groups, parents don't expend significantly more energy raising chicks.
[5] Source: Bennet et al. (1995). Estimate was obtained by integrating the energy budgets of male and female hand-reared chicks over all age intervals and then averaged males and females together.
[6] Source: Ulenaers and van Vessem (1994). Estimate was obtained by integrating intake per day over a period of 10 weeks.
[7] Source: Dunn (1975). Estimate was obtained by integrating food intake over 5-day age intervals. The values used for integration were estimated from a graph (provided in the reference) of total food intake per bird per day versus days of age.
[8] Source: Dunn (1980). Estimate was obtained by integrating food intake over 5-day age intervals. The values used for integration were estimated from a graph (provided in the reference) of total food intake per bird per day versus days of age.
[9] Source: Langham (1972) and Pearson (1964). Estimate was obtained using weight at age data from Langham (1972) and Pearson's (1964) equation for seabird food requirements (described in Langham, 1972) to estimate food requirements per day. This was integrated over the entire chick period, assuming the chick period is 25 days.
[10] Source: Schekkerman and Visser (2001). Estimate was obtained by estimating daily metabolized energy at 5-day age intervals from a graph of metabolized energy versus age. Metabolized energy was divided by a digestive efficiency of 69.9% (from Schekkerman and Visser, 2001) to estimate gross energy consumed per day, and integrated across the entire chick period.
[11] Source: Manseau and Gauthier (1993). Manseau and Gauthier (1993) provided data for the percent time spent feeding and food intake per hour for grass and sedge meadows. To determine the number of hours spent feeding per day, it was assumed that available feeding time was 12 hrs/day and multiplied by the percent time spent feeding. The estimate of number of hours spent feeding per day was multiplied by food intake per hour (average of grass and sedge), and integrated across entire chick period.
[12] Source: Penney and Bailey (1970). Estimate was obtained by averaging the mean total food consumed per bird in 8 weeks for both experimental groups.
[13] Source: Perry et al. (1986). Estimate was obtained by averaging daily feed intake values from both experimental time periods and all pens for Diet 2 (which was an invertebrate diet). The daily average was multiplied by the number of days from hatch to fledge (i.e., 62 days) to get total consumed.
[14] For data sources where intake was provided as kJ/day, it was necessary to convert to g/day. For piscivores, an average of 5 kJ/g was used (Cherel and Ridoux, 1992; Perez 1994). For invertebrate consumers, an average of energy to weight ratio data was used from benthic invertebrate data provided in Mendonca et al. (2007), and converted to wet weight using 0.22 g dry weight/g wet weight (from Nixon and Ovaitt, 1973) to obtain a final estimate of 5.08 kJ/g.

HEA with Trophic Web Model

This model for scaling required compensatory restoration and uses HEA with a trophic web model to calculate the required area of restored habitat to produce the same biomass as lost due to a spill. Scaling methods used here were initially developed for use in the *North Cape* case, as described in French et al. (2001), French McCay and Rowe (2003) and French McCay et al. (2003a). These methods have also been used in several other cases, as well as in successful claims for 23 cases submitted by the Florida Department of Environmental Protection to the U.S. Coast Guard, National Pollution Fund Center (French McCay et al., 2003b).

The habitat restoration model is based on food chain transfers, such that equivalent production at the same trophic level as the losses is produced by the restoration project. The approach uses energetic efficiencies to scale across trophic levels. Benefits of habitat to each trophic level are estimated by assuming that the production of consumers is proportional to prey production gained by the restoration of habitat. The habitat restoration model balances the production foregone losses with trophically equivalent production, discounting future gains in compensatory production relative to present losses such that interest is paid, analogous to economic discounting (French McCay and Rowe, 2003).

The basis for using this model is that restoration should provide equivalent quality fish and invertebrate biomass to compensate for the lost fish and invertebrate production. Likewise for wildlife, restoration should also replace the wildlife biomass that was lost. Equivalent quality implies same or similar species with equivalent ecological role and value for human uses. The equivalent production or replacement should be discounted to present-day values to account for the interim loss between the time of the injury and the time when restoration provides equivalent ecological and human services.

Habitat creation or preservation projects have been used to compensate for injuries of wildlife, fish and invertebrates. The concept is that the restored habitat leads to a net gain in wildlife, fish and invertebrate production over and above that produced by the location before the restoration. The size of the habitat (acreage) is scaled to just compensate for the injury (interim loss).

In the model developed by French McCay and Rowe (2003), the habitat may be seagrass bed, saltmarsh, oyster reef, freshwater or brackish wetland, or other structural habitats that provide such ecological services as food, shelter, and nursery habitat and are more productive than open bottom habitats. The injuries are scaled to the new primary (plant) or secondary (e.g., benthic) production produced by the created habitat, as the entire food web benefits from this production. A preservation project that would avoid the loss of habitat could also be scaled to the production preserved. The latter method would only be of net gain if the habitat is otherwise destined to be destroyed. In this analysis, it is assumed that only habitat creation projects would be undertaken.

The approach used here for scaling the size of the needed project is to use primary production to measure the benefits of the restoration. The total injuries in kg are translated into equivalent plant (angiosperm) production as follows. Plant biomass passes primarily through the detrital food web via detritivores consuming the plant material and attached microbial communities. When macrophytes are consumed by detritivores, the ecological efficiency is low because of the

high percentage of structural material produced by the plant, which must be broken down by microorganisms before it can be used by the detritivore. Each species group is assigned a trophic level relative to that of the detritivores. If the species group is at the same trophic level as detritivores, it is assumed 100% equivalent, as the resource injured would presumably have the same ecological value in the food web as the detritivores. If the injured resource preys on detritivores or that trophic level occupied by the detritivores, the ecological efficiency is that for trophic transfer from the prey to the predator. Values for production of predator per unit production of prey (i.e., ecological efficiency) are taken from the ecological literature, as reviewed by French McCay and Rowe (2003). The ecological efficiencies assumed are in Table 2.

Table 2. Assumed ecological efficiencies for one trophic step (French McCay and Rowe, 2003).

Consumer	Prey/food	% Efficiency
Invertebrate or finfish	Macrophyte	0.023
Invertebrate or finfish	Microalgae	10
Invertebrate	Microorganisms	20
Invertebrate or finfish	Detritivores	10
Invertebrate or fish	Invertebrate	20
Invertebrate or fish filter feeder	Plankton	20
Medium (200-1000g) fish piscivore	Finfish	10
Large (>1kg) fish piscivore	Finfish	4
Reptiles, amphibians	Invertebrates	20
Reptiles (piscivore/predator)	Finfish/Invertebrates	20
Birds, mammals (herbivores)	Macrophyte	0.03
Birds, mammals	Invertebrate	2
Birds, mammals (piscivores)	Finfish	2

The equivalent compensatory amount of angiosperm (plant) biomass of the restored resource is calculated as kilograms of injury divided by ecological efficiency. The ecological efficiency is the product of the efficiency of transfer from angiosperm to invertebrate detritivore and efficiency from detritivore to the injured resource, accounting for each step up the food chain from detritivore to the trophic level of concern. Table 3 lists the composite ecological efficiency relative to benthic invertebrate production for each trophic group evaluated in the modeling.

Table 3. Composite ecological efficiency relative to benthic invertebrate production by trophic group.

Species Category	Trophic Level	Ecological Efficiency Relative to Benthic Detritivores (%)
Fish and Invertebrates:		
Small pelagic fish	planktivorous	20
Large pelagic fish	piscivores/predators	0.8
Demersal fish	bottom feeders	10
Crustaceans	bottom feeders	20
Benthic invertebrates	filter/bottom feeder	100
Birds:		
Waterfowl	bottom feeders	2
Seabirds	piscivores	0.4
Waders	piscivores	0.4
Shorebirds	bottom feeders	2
Raptors	piscivores	0.4
Kingfishers	piscivores	0.4

Species Category	Trophic Level	Ecological Efficiency Relative to Benthic Detritivores (%)
Other wildlife:		
Herbivorous mammals	herbivores	0.03
Reptiles, amphibians	invertebrate feeders	20
Reptiles	piscivores	4

The productivity gained by the created habitat is corrected for less than full functionality during recovery using a sigmoid recovery curve. Discounting at 3% per year is included for delays in production because of development of the habitat, and delays between the time of the injury and when the production is realized in the restored habitat. The equations and assumptions may be found in French McCay and Rowe (2003).

The needed data for the scaling calculations are:

- number of years for development of full function in a restored habitat;
- annual primary production rate per unit area (P) of restored habitat at full function (which may be less than that of natural habitats);
- delay before restoration project begins; and
- project lifetime (years the restored habitat will provide services).

The calculations below are based on emergent marsh wetland restoration, as this habitat is most frequently used for compensation; thus, it is used for estimating the potential restoration needs and Natural Resource Damage Assessment (NRDA) costs.

Wetland Restoration

Restoration scaling calculations for wetland were performed following the methods in French McCay and Rowe (2003). It is assumed that the emergent marsh requires 15 years to reach full function (based on LA DEQ et al., 2003), ultimately reaching 100% of natural habitat productivity, the restoration begins in 2014 (12 years after the spill), and the project lifetime is 20 years (LA DEQ et al., 2003).

Klopatek and Stevens (1978) evaluated primary production of various emergent macrophytes in a southeastern Wisconsin freshwater marsh ecosystem. The marsh area evaluated was approximately 2,025 ha, including a 600-ha shallow water impoundment. The marsh vegetation included lowland forest, shrub carr and submergent aquatics, with predominately edge meadow and emergent aquatic communities. With estimates for litter loss and belowground production, annual net primary production ranged from 1,181 g/m^2/year for *Carex lacustris* to nearly 3200 g/m^2/year for *Typha latifolia*. They also noted that if the emergent, submergent, free-floating macrophytes are included (plus possible algae production), the net annual primary production for the marsh system probably lies between 2,800 and 3,800 g/m^2/year. Table 4 provides a summary of the net annual primary production (g/m^2/year) from Klopatek and Stevens (1978) that was used for this (202 Rouge River NRDA) restoration scaling.

Table 4. Summary of net annual primary production rates used for wetland restoration scaling (Source: Klopatek and Stevens 1978).

Macrophyte Species	Net annual primary production ($g/m^2/yr$)	Notes
Typha latifolia	3200	Includes above and below ground
Scirpus fluviatilis	1533	Includes above and below ground
Carex lacustris	1181	Includes above and below ground
Phalaris arundinacea	2028	Aboveground only
Salix interior	1902	Includes above and below ground; Annual net production is likely underestimated because it was based on a single sample taken in September.

For the injured resources, all weights are as wet weight and dry weight is assumed 22% of wet weight (Nixon and Oviatt, 1973). The ratio of carbon to dry weight is assumed 0.45 (French et al., 1996). For the wildlife, the body mass per animal (from French et al. [1996] or from Sibley [2003]) is used to estimate injury in kg (multiplying by number killed and summing each species category).

F.3 Restoration Scaling Results

The injury totals compensated are listed in Tables 5 and 6, along with restoration areas by species group. Compensation for marsh injuries (to the entire habitat) are developed in Table 7.

Table 5. Scale of restoration (acres) for compensation of injuries to wildlife, fish and invertebrates, assuming fully restored habitat produces 2,800 g dry weight/m^2 annually as natural habitat dominated by *Carex lacustris* plus mixed species (see text).

Species Category	Total Injury (kg, wet weight)	Trophic Level	Production Yield (%)	Compensatory Production (kg, dry weight)	Habitat Area (m2)	Habitat Area (acres)
Small pelagic fish	2.2	planktivorous	20	103	6	0.001
Large pelagic fish	15.6	piscivores/ predators	0.8	18,274	1027	0.254
Demersal fish	211	bottom feeders	10	19,774	1112	0.275
Small fish for birds	332,449	bottom feeders	20	15,577,788	875641	216.4
Invertebrates for birds	59,842	filter/bottom feeder	100	560,808	31524	7.789
Amphibians	3.35	bottom feeders	20	157	9	0.002
Reptiles	18.53	bottom feeders	20	868	49	0.012
Reptiles	20.26	piscivores/ predators	4	4,747	267	0.066
Muskrats	369.9	herbivores	0.03	11,555,104	649523	160.5
Totals:						
Subtotal fish and invertebrates	392,409			16,176,748	909,309	224.69
Subtotal herps, mammals	412			11,560,876	649,847	160.57
Total all species	392,821			27,737,624	1,559,156	385.3

Table 6. Scale of restoration (acres) for compensation of injuries to wildlife, fish and invertebrates, assuming fully restored habitat produces 3,800 g dry weight/m^2 annually as natural habitat dominated by *Typha latifolia.*

Species Category	Total Injury (kg, wet weight)	Trophic Level	Production Yield (%)	Compensatory Production (kg, dry weight)	Habitat Area (m2)	Habitat Area (acres)
Small pelagic fish	2.2	planktivorous	20	106	4	0.001
Large pelagic fish	15.6	piscivores/ predators	0.8	18,868	789	0.195
Demersal fish	211	bottom feeders	10	20,416	854	0.211
Small fish for birds	332,449	bottom feeders	20	16,083,602	672,586	166.2
Invertebrates for birds	59,842	filter/bottom feeder	100	579,018	24,213	5.983
Amphibians	3.35	bottom feeders	20	162	7	0.002
Reptiles	18.53	bottom feeders	20	896	37	0.009
Reptiles	20.26	piscivores/ predators	4	4,901	205	0.051
Muskrats	369.9	herbivores	0.03	11,930,301	498,903	123.3
Totals:						
Subtotal fish and invertebrates	392,409			16,702,010	697,477	172.6
Subtotal herps, mammals	412			11,936,260	499,152	123.3
Total all species	392,821			28,638,270	1,197,599	295.9

Restoration for Complete Loss of Habitat

If the entire habitat is killed, such as by lethal oiling of vegetation, and that same habitat is replanted, a simple HEA calculation (NOAA, 1997) can be performed such that the amount of habitat required is calculated accounting for the recovery of the functionality of the habitat. The equivalent area should be discounted to present-day values (i.e., at 3% per year of delay) to account for the interim loss between the time of the injury and the time when restoration provides equivalent ecological services. The approach and equations are described in NOAA (1997, 1999).

Results – Restoration Requirements for Habitat Injuries

The areas of habitat oiled with more than 1mm of oil, which has been shown to be lethal to wetlands (French McCay, 2009), are listed in Table 8. Areas of habitat restoration which would compensate for these losses (using a 20-year project life beginning 12 years after the spill, and assuming 15 years for recovery) are also listed in Table 8. Note that these restorations requirements would be in addition to those listed in the previous section.

Table 7. Total shoreline (wetland) area oiled by >1mm (>1kg/m^2) of oil, which would be lethal to vegetation and all associated biota; and scale of in-kind wetland restoration using the standard HEA model (assumes the same wetland type is fully restored as was injured).

Habitat Type	Area Oiled (m^2)	Area of Compensatory Restoration (m^2)	Area of Compensatory Restoration (acres)
Wetland	26,959	916.62	0.226

The amounts of wetland required in compensation for the quantified wildlife, fish and invertebrate injuries are summarized in Table 8.

Table 8. Scale of restoration (acres) for compensation of injuries to wildlife, fish and invertebrates.

Dominant Plant	Fish	Birds	Herps	Mammals	Marsh	Total
Typha latifolia	0.407	172	0.062	123	0.226	296
Carex lacustris plus mixed spp.	0.530	224	0.080	161	0.226	385

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