ESTIMATE OF TOTAL INJURY TO DIAMONDBACK TERRAPINS FROM THE CHALK POINT OIL SPILL

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February 25, 2002

I. INTRODUCTION

This report was prepared by a subgroup of the Wildlife Injury Workgroup, which was established by the Natural Resource Trustee Council conducting the natural resource damage assessment of the April 7, 2000 oil spill at Chalk Point, Maryland. The report presents a comprehensive estimate of injuries to diamondback terrapins *(Malaclemys terrapin)* inclusive of acute mortality, reduced survivability of hatchlings due to the oil and the loss of production in the next generation of terrapins following the spill. Quantification of these injuries is presented in terms of terrapin years foregone. The trustees have found this to be a useful metric for purposes of identifying and evaluating restoration projects. These calculations are based in part on injury estimates found in the reports entitled: *Acute Mortality of Diamondback Terrapins from the PEPCO Oil Spill, Patuxent River* (Michel, et al., 2001) and *Comparison of northern diamondback terrapin (Malaclemys terrapin terrapin) hatching success among variably oiled nesting sites along the Patuxent River following the Chalk Point Oil Spill of April 7, 2000* (Wood, et al., 2001).

Estimates of the number of terrapin-years lost from acute mortality and next-generation production foregone were obtained using methods similar in concept to those found in the bird injury quantification report prepared for the *North Cape* oil spill natural resource damage assessment (Sperduto et al., 1999). The additional loss of terrapin years due to an increase in hatchling mortality in 2000 because of the oil spill is estimated by reducing survival of this life stage by 10% below normal (without oil) baseline.

The diamondback terrapin ranges from the Gulf Coast of Texas to Cape Cod, Massachusetts, however, little information is available on the life history of this species. Thus, some data reported for several turtles belonging to the family Emydidae were used in the calculations. The average age of the population and the annual survival of terrapins in the absence of the oil spill were used to determine the injury in terrapin-years lost for the juveniles and adults killed by the spill (i.e., direct terrapin-years). Production foregone (i.e., the terrapin-years lost from the next generation that would have otherwise been produced by the terrapins that were killed directly by the oil) was estimated using the number of years an average-aged terrapin would have produced hatchlings and the number of terrapin-years the hatchlings would have been expected to live. The loss of hatchlings due to the oil was based on the field work of Wood, et al. (2001) and their best professional judgement (Wood, et al. 200-2002). In cases where a range of choices was available, a balance was sought between choosing parameter values that were either extremely high or extremely low.

The analysis results in an estimate of 615.6 lost discounted terrapin-years from the direct mortality of 122 adults and juveniles. An additional 3,792.7 discounted terrapin-years were lost due to production foregone in the next generation. And an additional 836.3 discounted terrapin years were lost due to the 10% increase in mortality of hatchlings in 2000. The total estimated injury is 5,244.6 lost discounted terrapin-years.

[1] Hinkeldey and Michel: Research Planning, Inc.; Tomasi, Greer, Byrd, and Kicklighter: ENTRIX, Inc.; Wood: Richard Stockton College; English and Meade: NOAA.

II. METHODS

A. Direct Terrapin-Years Lost

The direct terrapin-years lost is estimated in three steps. First, the average age of a Patuxent River terrapin is estimated. It is assumed that all terrapins killed due to the oil spill were the average age. Second, it is recognized that there is less than a 100% probability that all terrapins alive in a given year survive to the next age class. The expected value of terrapin-years lost is estimated each year. The average survival rate is applied, and those expected to live to the next age class contribute one terrapin-year, while those who die sometime during the year are assumed to contribute ½ terrapin-year. Third, the terrapin years are discounted, and summed over future potential years of life --- from the average age through the maximum age.

1. Age-Class Distribution and Average Age of the Population

An age-class distribution for diamondback terrapins was created using survival rates from terrapin studies as well as other turtle species in the emydid family. Roosenburg (1990a), Wood, et al. (2000-2002) and others report that terrapin egg-to-hatchling survival rates range between 1% and approximately 30% in the wild. A survival rate of 20% was assumed for purposes of this study (Table 1). Survival rates for hatchling to year one, juvenile, and adult age classes for terrapins are unknown, however. Therefore, these rates were gathered for other emydid species from Heppell (1998) and Natureserve (2001) and applied to the Patuxent River terrapin population (Table 2). An annual survival rate was calculated for each age group: hatchlings (0-1 yrs), juveniles (1-4 yrs), subadults (4-7 yrs), and adults (> 7 yrs). These age groups were chosen based on Heppell's compilation of age group lengths for representatives of the emydid family (1998) and data from Roosenburg (1990a).

Table 1. Population parameters for Patuxent River diamondback terrapins

POPULATION PARAMETERS	VALUES
Population size	4,698 individuals[a]
Max attainable age	50 years
Survivorship	
Eggs to hatchling	0.20
Hatchlings to year 1	0.415[b]
Hatchlings (0-1 yr: combined eggs to hatchling + hatchling survival to year 1)	0.083[b]
Juveniles (1-3 years)	0.662 annually[b]
Subadults (4-6 yr)	0.862 annually[b]
Adults (7+)	0.847 annually[b]
Age at 1st reproduction- males	4-7 yrs
Age at 1st reproduction- females	8-13 yrs
Ratio of Females: Males	3:1
Clutch Frequency/yr	2 (range 1-3)
Clutch size	13 (range 7-22)
Expected No. of Eggs/Female per yr	26

a Michel, et al., 2001

[b]denotes values extrapolated from several species in emydid family

The overall hatchling survival rate was defined as the survival of the egg to hatchling multiplied by the survival of hatchlings to year one age classes. The probability of hatchling survival to year one was calculated by multiplying the egg to hatchling survival rate, 20% (Woods et. al., 2000-2002), by the average survival rate to year one and year one to year two from slider and painted turtles (.415, from juvenile category). Slider and painted turtle hatchling survival rates from Heppell (1998) were not used because they combined the egg to hatchling survival and survival to year one age classes, while egg to hatchling survivorship for terrapins was already available. It was not possible, given available information, to separate the two values (egg to hatchling survival and survival to year one) from the Heppell study data, so the slider turtle juvenile survival rates to year one and the painted turtle survival rates from year 1 to year 2 were used as surrogates for the terrapin hatchling survival rate. This gave a survival probability of 0.083 (0.415 * .20), the probability that a terrapin would survive to become a one year old juvenile once the egg was laid. These values appear to be reasonable estimates, given that the worst-case scenario for hatchling survival rates for the slider turtle was reported as .010 (Table 2).

Juvenile terrapin survivorship was obtained by taking the average of all survivor rates from juvenile slider and painted turtles (.662). The survival rate for terrapin subadults and adults was calculated by taking an average of all rates given for slider, painted, and eastern box turtles (.862 and .847), respectively for subadults and adults.

Table 2. Annual survival rates for emydidae turtles (Heppell 1998).

	Hatchlings[a]	**Juveniles**[b]	**Subadults**	**Adults**
	(0-1yrs)	**(1-3 yrs)**	(4-6 yrs)	(7+)
Slider Turtle (Heppell 1998)				
worst case	0.010	**0.248**(yr 1), .774 (yrs 2-3)	0.774	0.774
medium case	0.105	**0.539** (yr 1), .829 (yrs 2-3)	0.814	0.814
best case	0.275	0.829 (yrs 2-3)	0.854	0.854
mean	0.130	0.6438	0.814	0.814
Painted Turtle				
Wilbur 1975	0.080	0.82 (yr 1-3)	0.82	
Tinkle et al. 1981	0.670	0.76 (yr 1-3)	0.76	0.76
Mitchell 1988	0.193	**0.457** (yr 1-2)	0.944 (yr 3-7)	0.96
mean	0.314	0.679	0.841	0.846
Eastern Box Turtle				
Natureserve 2001			0.93	.93-.94
				74-.92
Average	.222	0.662	0.862	0.847

a Hatchling rates represent egg to hatchling survival plus hatchling to year one.

b Bold-faced juvenile survival rates were used for terrapin hatchling to year one survival rates (0.248, 0.539, 0.457, with a mean of 0.415). For years two and three, a .662 average survival rate is used . For years four, five and six, a .862 average survival rate is used. And for years seven through fifty, a .847 average survival rate is used.

Using the estimated survival rates for each age group, and a maximum attainable age of 50 years (Roosenburg, 1990a), an age-class table was created (Table 3). It was determined that terrapin hatchlings have an 8.3% probability of surviving to age one. To obtain the probabilities of surviving to the second year, the average survival rate of the second year (.662) is multiplied by the survival probability from the previous year (.083), and so on, for a total of 50 years. The third column is the probability that a hatchling lives to the associated age.

To obtain the average age of the population requires two steps. First, the probability that a randomly chosen terrapin is a given age is computed (this is shown in Table 3, column 4). This equals the probability that a hatchling lives to that age (Table 3, column 3) divided by the sum of these probabilities (the sum of column 3). Then, the average age is computed. This is done by multiplying each age class (column 1) by the probability that an individual is that many years old (column 4), the result of which is shown in column 5, and adding up all the possible ages.[2]

The resulting average age of the Patuxent River diamondback terrapin population, based on the data in Table 3, is estimated to be 6.01 years. It is assumed that all terrapins killed as a result of the oil spill are 6 years old.

[2] More formally, let $pr_{x-1,x}$ be the conditional probability that a hatchling survives to age x, given that it has survived to age x-1. Then the probability that a hatchling survives to age x is $pr_x = pr_{x-1}(pr_{x-1,x})$ with $pr_0 = 1$. If $P = \Sigma_x\, pr_x$, then the probability that an individual chosen at random is age x is $f_x = pr_x/P$. The average age in the population is then the usual expected value $E(x) = \Sigma_x\, xf_x$.

Table 3. Average age of juvenile and adult terrapins

1	2	3	4	5
Age	**Annual Survival Rate**	**P(age)**	**f(age)**	**f(age)*Age**
1	0.083	0.083000	0.215646	0.215646
2	0.662	0.054946	0.142758	0.285516
3	0.662	0.036374	0.094506	0.283517
4	0.862	0.031355	0.081464	0.325856
5	0.862	0.027028	0.070222	0.351109
6	0.862	0.023298	0.060531	0.363188
7	0.847	0.019733	0.051270	0.358890
8	0.847	0.016714	0.043426	0.347405
9	0.847	0.014157	0.036782	0.331034
10	0.847	0.011991	0.031154	0.311540
11	0.847	0.010156	0.026387	0.290262
12	0.847	0.008602	0.022350	0.268202
13	0.847	0.007286	0.018931	0.246097
14	0.847	0.006171	0.016034	0.224479
15	0.847	0.005227	0.013581	0.203714
16	0.847	0.004427	0.011503	0.184049
17	0.847	0.003750	0.009743	0.165633
18	0.847	0.003176	0.008252	0.148543
19	0.847	0.002690	0.006990	0.132806
20	0.847	0.002279	0.005920	0.118407
21	0.847	0.001930	0.005015	0.105305
22	0.847	0.001635	0.004247	0.093441
23	0.847	0.001385	0.003597	0.082742
24	0.847	0.001173	0.003047	0.073129
25	0.847	0.000993	0.002581	0.064522
26	0.847	0.000841	0.002186	0.056836
27	0.847	0.000713	0.001852	0.049991
28	0.847	0.000604	0.001568	0.043911
29	0.847	0.000511	0.001328	0.038521
30	0.847	0.000433	0.001125	0.033752
31	0.847	0.000367	0.000953	0.029541
32	0.847	0.000311	0.000807	0.025828
33	0.847	0.000263	0.000684	0.022560
34	0.847	0.000223	0.000579	0.019688
35	0.847	0.000189	0.000490	0.017166
36	0.847	0.000160	0.000415	0.014955
37	0.847	0.000135	0.000352	0.013019
38	0.847	0.000115	0.000298	0.011325
39	0.847	0.000097	0.000252	0.009845
40	0.847	0.000082	0.000214	0.008552
41	0.847	0.000070	0.000181	0.007425
42	0.847	0.000059	0.000153	0.006442
43	0.847	0.000050	0.000130	0.005586
44	0.847	0.000042	0.000110	0.004842
45	0.847	0.000036	0.000093	0.004194
46	0.847	0.000030	0.000079	0.003631
47	0.847	0.000026	0.000067	0.003143
48	0.847	0.000022	0.000057	0.002718
49	0.847	0.000018	0.000048	0.002351
50	0.847	0.000016	0.000041	0.002032
sum		0.384889	1.000000	**6.012886**

2. Estimated Lost Direct Discounted Terrapin-Years

In this section the expected number of lost discounted terrapin-years for the juvenile and adult turtles killed by the spill is estimated. The adult survival rate is incorporated into the discounted survival rate formula for each year that an adult terrapin could have lived in the absence of the spill. Each year there are two possibilities; either the terrapin lives one more year or it dies sometime during the year. If the terrapin lives (with a survival probability of 0.847), then it provides one terrapin-year. If a terrapin dies (with probability equal to 1-0.847 = 0.153), it is assumed that it dies mid-way through the year, and so provides ½ a terrapin-year. These terrapin-years are then discounted at the appropriate discount rate (3%).[3] It was previously estimated that the average aged turtle in this spill was 6.012886 years of age and will be 7 the first year following the spill, therefore having the possibility to live 44 more years of his maximum attainable age after the spill. Summing over all years results in the discounted terrapin-years (DTYs) per adult killed.[4]

This calculation is shown in Table 4. The first column is the number of years after the spill, and runs from zero to 44; the second column is the age of the terrapin. The third column is the annual survival probability. The fourth column is the terrapin-years added by those who survive from one age to the next. This is the probability of surviving to an age (called P(Age) in Table 3), times the number of terrapin-years added (equal to one for survivors). The fifth column is the terrapin-years contributed by those who die during the year. This is the probability of surviving to the prior age (i.e. P(age-1)) times the probability of dying (0.153) times the terrapin-years added (1/2 for those who die). The sixth column is the discount factor. The seventh column multiplies the discount factor times the sum of entries in columns four and five. Adding up column seven gives the lost DTYs per adult killed, equal to 5.046. The lost DTYs is then multiplied by 122, total direct terrapin mortality (acute injury) from the spill (Michel, et al., 2001). Using these values, the number of direct discounted terrapin-years lost is estimated to be 615.6.

To illustrate how the calculation of direct injury works, absent the spill there would have been 122 terrapins that were six years old. In the first year after the spill, $122 \times 0.847 = 103$ would have lived and $122 \times 0.153 = 19$ would have died. So, in this year there would have been 103 + (1/2)19 = 112.5 terrapins-years, which equates to 109.2 discounted terrapin-years. In the second year, $122 \times 0.847^4 \times 0.847 = 87$ terrapins would have lived to provide one additional terrapin-year, while $122 \times 0.847 \times 0.153 = 16$ would have died and provided ½ terrapin-year. This equates to 87 + (1/2)16 = 95 current terrapin-years, or 90 discounted terrapin-years. These numbers can be obtained (except for small differences due to rounding) by multiplying the entries in column seven by 122. Doing this calculation for each year and adding up the years from age six to fifty yields the estimated direct injury to terrapins.

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[3] NOAA's "Scaling Compensatory Restoration Actions: Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990" recommends the use of anannual discount rate of 3% to approximate today's value of future terrapin-years lost; this will be the discount rate used for the calculations found in this report.

[4] For adults, the surrvial probability is a constant, pr (equal to 0.847). If the annual percentage discount rate is r, the lost discounted terrapin-years per adult killed is given by $L = \Sigma_{t\in[1,44]} (1+r)^{-t} \{pr^t + pr^{t-1}(1 - pr)(1/2)\}$. The first term is the discount factor. The second term is the sum of the terrapin years contributed by those who live from age t-1 to age t and by those who live to t but die before t+1 and so only contribute ½ a terrapin-year.

Table 4. Lost direct discounted terrapin-years

1	2	3	4	5	6	7
Year After Spill	**Age**	**Annual Survival Rate**	**Terrapin Years per Survivor**	**Terrapin Years per Deceased**	**Discount Factor**	**DTY**
0	6					
1	7	0.847	0.847000	0.076500	0.970874	0.896602
2	8	0.847	0.717409	0.064796	0.942596	0.737303
3	9	0.847	0.607645	0.054882	0.915142	0.606306
4	10	0.847	0.514676	0.046485	0.888487	0.498584
5	11	0.847	0.435930	0.039373	0.862609	0.410001
6	12	0.847	0.369233	0.033349	0.837484	0.337156
7	13	0.847	0.312740	0.028246	0.813092	0.277253
8	14	0.847	0.264891	0.023925	0.789409	0.227994
9	15	0.847	0.224363	0.020264	0.766417	0.187486
10	16	0.847	0.190035	0.017164	0.744094	0.154175
11	17	0.847	0.160960	0.014538	0.722421	0.126783
12	18	0.847	0.136333	0.012313	0.701380	0.104258
13	19	0.847	0.115474	0.010429	0.680951	0.085734
14	20	0.847	0.097807	0.008834	0.661118	0.070502
15	21	0.847	0.082842	0.007482	0.641862	0.057976
16	22	0.847	0.070167	0.006337	0.623167	0.047675
17	23	0.847	0.059432	0.005368	0.605016	0.039205
18	24	0.847	0.050339	0.004547	0.587395	0.032239
19	25	0.847	0.042637	0.003851	0.570286	0.026511
20	26	0.847	0.036113	0.003262	0.553676	0.021801
21	27	0.847	0.030588	0.002763	0.537549	0.017928
22	28	0.847	0.025908	0.002340	0.521893	0.014742
23	29	0.847	0.021944	0.001982	0.506692	0.012123
24	30	0.847	0.018587	0.001679	0.491934	0.009969
25	31	0.847	0.015743	0.001422	0.477606	0.008198
26	32	0.847	0.013334	0.001204	0.463695	0.006741
27	33	0.847	0.011294	0.001020	0.450189	0.005544
28	34	0.847	0.009566	0.000864	0.437077	0.004559
29	35	0.847	0.008102	0.000732	0.424346	0.003749
30	36	0.847	0.006863	0.000620	0.411987	0.003083
31	37	0.847	0.005813	0.000525	0.399987	0.002535
32	38	0.847	0.004923	0.000445	0.388337	0.002085
33	39	0.847	0.004170	0.000377	0.377026	0.001714
34	40	0.847	0.003532	0.000319	0.366045	0.001410
35	41	0.847	0.002992	0.000270	0.355383	0.001159
36	42	0.847	0.002534	0.000229	0.345032	0.000953
37	43	0.847	0.002146	0.000194	0.334983	0.000784
38	44	0.847	0.001818	0.000164	0.325226	0.000645
39	45	0.847	0.001540	0.000139	0.315754	0.000530
40	46	0.847	0.001304	0.000118	0.306557	0.000436
41	47	0.847	0.001105	0.000100	0.297628	0.000358
42	48	0.847	0.000936	0.000085	0.288959	0.000295
43	49	0.847	0.000792	0.000072	0.280543	0.000242
44	50	0.847	0.000671	0.000061	0.272372	0.000199
sum						**5.045525**

B. Production Foregone

For the next component of turtle injury quantification, production foregone must be evaluated. This is accomplished in several steps. First, if a female survives to sexual maturity, it is assumed that she produces young.[5] Data from Table 1 are used to compute the expected number of hatchlings per female. Second, the expected DTYs provided by a hatchling from a female of any age is computed. This is the DTY per member of a cohort of hatchlings born of an average female who survives to a given age. Multiplying the expected number of hatchlings per female by the DTYs contributed by a hatchling gives the terrapin-years foregone from a female that survives to a given age. Third, using the annual survivorship for females, the expected number of females each year is computed. Finally, adding across years and discounting yields the lost DTYs from the production forgone.

1. Expected Hatchlings per Female

Using information in Table 1, each fecund female is assumed to produce 2 clutches per year (the midpoint of the range reported in Roosenburg (1990a)), with an average clutch size of 13 eggs. Thus, each female is expected to produce 26 eggs in a year. The probability of an egg producing a hatchling is 0.20. The expected number of hatchlings produced by a fecund female is $0.2 \times 26 = 5.2$. Fecundity is assumed to begin at age 8.

2. Discounted Terrapin-Years per Cohort Member

The DTYs contributed by a hatchling that is a member of a cohort born at a given time is computed by multiplying the probability of survival to a given age times the terrapin-years at that age (one for those that survive, and ½ for those that die), times the discount factor, summed over the potential ages of a hatchling (1 to 50). This is shown in Table 5. The first column is the age of a hatchling. The second column is the annual survival rate, i.e. the probability of surviving from one age to the next. The third column gives the probability of surviving to the associated age. This is the product of the annual survival rates for the previous years; for example, for the second year, $0.275 = 0.415 \times 0.662$, and so on for the other years. The fourth column is the terrapin-years added at the associated age. Just as with the adults, this is one terrapin year for each terrapin that survives and ½ terrapin-year for each one that dies. The fifth column is the discounted terrapin-years at that age; this multiplies the discount factor times the fourth column. Summing the fifth column yields the number of DTYs provided by a hatchling born into a cohort at any given time. This equals 2.095.

Note that this is essentially the same calculation as was carried out for the adult discounted terrapin-years lost, but incorporates the ages before age six. Since young terrapins are more likely to die in a given year than older ones, the DTY for a hatchling is less than for a terrapin that is known to have lived to age six.

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[5] It is assumed that those who do not survive to the next age class produce young before they die.

[7] Formally, the computation is that DTY per hatchling, H, is given by :

Table 5. Discounted terrapin-years per hatchling

1	2	3	4	5
Age	**Annual Surv Rate**	**P(age)**	**Terrapin Years**	**DTY per Hatchling**
1	0.415	0.415000	0.707500	0.686893
2	0.662	0.274730	0.637365	0.325068
3	0.662	0.181871	0.590936	0.208927
4	0.862	0.156773	0.578387	0.150441
5	0.862	0.135138	0.567569	0.125903
6	0.862	0.116489	0.558245	0.105367
7	0.847	0.098666	0.549333	0.087471
8	0.847	0.083570	0.541785	0.071930
9	0.847	0.070784	0.535392	0.059150
10	0.847	0.059954	0.529977	0.048641
11	0.847	0.050781	0.525391	0.039999
12	0.847	0.043012	0.521506	0.032892
13	0.847	0.036431	0.518215	0.027048
14	0.847	0.030857	0.515428	0.022243
15	0.847	0.026136	0.513068	0.018291
16	0.847	0.022137	0.511069	0.015041
17	0.847	0.018750	0.509375	0.012369
18	0.847	0.015881	0.507941	0.010171
19	0.847	0.013451	0.506726	0.008364
20	0.847	0.011393	0.505697	0.006878
21	0.847	0.009650	0.504825	0.005656
22	0.847	0.008174	0.504087	0.004651
23	0.847	0.006923	0.503462	0.003825
24	0.847	0.005864	0.502932	0.003145
25	0.847	0.004967	0.502483	0.002586
26	0.847	0.004207	0.502103	0.002127
27	0.847	0.003563	0.501782	0.001749
28	0.847	0.003018	0.501509	0.001438
29	0.847	0.002556	0.501278	0.001183
30	0.847	0.002165	0.501083	0.000973
31	0.847	0.001834	0.500917	0.000800
32	0.847	0.001553	0.500777	0.000658
33	0.847	0.001316	0.500658	0.000541
34	0.847	0.001114	0.500557	0.000445
35	0.847	0.000944	0.500472	0.000366
36	0.847	0.000799	0.500400	0.000301
37	0.847	0.000677	0.500339	0.000247
38	0.847	0.000574	0.500287	0.000203
39	0.847	0.000486	0.500243	0.000167
40	0.847	0.000411	0.500206	0.000138
41	0.847	0.000349	0.500174	0.000113
42	0.847	0.000295	0.500148	0.000093
43	0.847	0.000250	0.500125	0.000076
44	0.847	0.000212	0.500106	0.000063
45	0.847	0.000179	0.500090	0.000052
46	0.847	0.000152	0.500076	0.000043
47	0.847	0.000129	0.500064	0.000035
48	0.847	0.000109	0.500054	0.000029
49	0.847	0.000092	0.500046	0.000024
50	0.847	0.000078	0.500039	0.000019
sum				**2.094830**

3. Lost Discounted Terrapin- Years from Production Foregone

Several steps are used to compute the number of terrapin-years produced from each hatchling that would have been born in absence of the spill. First, the expected number of females that would have lived to a given age but for the spill is estimated. This is given by the estimated direct terrapins mortality (122) times the ratio of females to total terrapins (0.75, from Table 1), times the probability that a female survives to that age (column 3). This calculation is shown in column 4 of Table 6. Second, multiplying by the expected number of hatchlings per female ($26 * 0.2 = 5.8$) times the number of females of that age (column 4) gives the size of a cohort of hatchlings born at that date in column 5. Note that there will be no hatchling years lost in the first two years following the spill, as the terrapins would be in age classes 6 and 7 and would not yet be able to reproduce. In the previous section it was calculated that a hatchling born at a given date provides 2.095 (rounded) DTYs, where these terrapin-years are realized in years after the date of birth, discounted back to the date of birth. This 2.095 DTYs per hatchling is a constant, irrespective of the date of birth. Multiplying the size of the hatchling cohort by the 2.095 DTYs per hatchling (shown in Table 6, column 6) results in DTYs for a given cohort (column 7), as of the date of birth of this cohort. For example, for the cohort born in the second year after the spill, 715.1 discounted terrapin-years are produced. This then needs to be discounted from the date of birth (year two following the spill) back to the spill date. This final discounting step is shown in column 8. Summing over all the future cohorts through the maximum age (i.e. the sum of column 7) yields the DTYs from the production foregone.[7] The number of DTYs from hatchlings lost due to acute injury to adults for the Patuxent River population after the spill is estimated to be 3,792.8.

Table 6. Lost discounted terrapin-years for production foregone

1	2	3	4	5	6	7	8
Year After Spill	**Age of Adults**	**Adult P(age)**	**Expected Number of Females**	**Offspring Cohort Size**	**DTY per Cohort Member**	**DTY per Cohort**	**Discounted DTY per Cohort**
0	6		91.500				
1	7	0.847	77.501				
2	8	0.717	65.643	341.343	2.095	715.056	674.009
3	9	0.608	55.600	289.118	2.095	605.652	554.258
4	10	0.515	47.093	244.883	2.095	512.988	455.783
5	11	0.436	39.888	207.416	2.095	434.501	374.804
6	12	0.369	33.785	175.681	2.095	368.022	308.213
7	13	0.313	28.616	148.802	2.095	311.715	253.452
8	14	0.265	24.238	126.035	2.095	264.022	208.422
9	15	0.224	20.529	106.752	2.095	223.627	171.391
10	16	0.190	17.388	90.419	2.095	189.412	140.940
11	17	0.161	14.728	76.585	2.095	160.432	115.899
12	18	0.136	12.474	64.867	2.095	135.886	95.308
13	19	0.115	10.566	54.943	2.095	115.095	78.374
14	20	0.098	8.949	46.536	2.095	97.486	64.450
15	21	0.083	7.580	39.416	2.095	82.570	52.999
16	22	0.070	6.420	33.386	2.095	69.937	43.583
17	23	0.059	5.438	28.278	2.095	59.237	35.839
18	24	0.050	4.606	23.951	2.095	50.174	29.472
19	25	0.043	3.901	20.287	2.095	42.497	24.235
20	26	0.036	3.304	17.183	2.095	35.995	19.930
21	27	0.031	2.799	14.554	2.095	30.488	16.389
22	28	0.026	2.371	12.327	2.095	25.823	13.477
23	29	0.022	2.008	10.441	2.095	21.872	11.082
24	30	0.019	1.701	8.844	2.095	18.526	9.113
25	31	0.016	1.440	7.490	2.095	15.691	7.494
26	32	0.013	1.220	6.344	2.095	13.291	6.163
27	33	0.011	1.033	5.374	2.095	11.257	5.068
28	34	0.010	0.875	4.552	2.095	9.535	4.167
29	35	0.008	0.741	3.855	2.095	8.076	3.427
30	36	0.007	0.628	3.265	2.095	6.840	2.818
31	37	0.006	0.532	2.766	2.095	5.794	2.317
32	38	0.005	0.450	2.343	2.095	4.907	1.906
33	39	0.004	0.382	1.984	2.095	4.156	1.567
34	40	0.004	0.323	1.681	2.095	3.521	1.289
35	41	0.003	0.274	1.423	2.095	2.982	1.060
36	42	0.003	0.232	1.206	2.095	2.526	0.871
37	43	0.002	0.196	1.021	2.095	2.139	0.717
38	44	0.002	0.166	0.865	2.095	1.812	0.589
39	45	0.002	0.141	0.733	2.095	1.535	0.485
40	46	0.001	0.119	0.621	2.095	1.300	0.398
41	47	0.001	0.101	0.526	2.095	1.101	0.328
42	48	0.001	0.086	0.445	2.095	0.933	0.269
43	49	0.001	0.073	0.377	2.095	0.790	0.222
44	50	0.001	0.061	0.319	2.095	0.669	0.182
sum							**3792.759**

C. Increased Hatchling Mortality

Another component of injury is increased hatchling mortality during the 2000 nesting season. It was assumed that the oil had no effect on hatchling mortality in other years. This component incorporates the reduction of the likelihood that an egg laid in the 2000 nesting season will produce a viable hatchling which survives to the following year. The injury is measured as the estimated discounted terrapin years provided by the 2000 hatchling cohort in baseline conditions minus the estimated discounted terrapin years provided by the 2000 hatchling cohort, including an oil effect on hatchling success relative to baseline. The oil effect was assumed to be a 10% reduction in the first-year hatchling survival rate.

1. Baseline Discounted Terrapin-Years of 2000 Hatchlings

Baseline discounted terrapin years that would have been provided by the 2000 cohort is estimated in three steps: (1) the number of eggs that would have been laid is estimated based on baseline population parameters; (2) the number of expected hatchlings from those eggs is estimated; and (3) the number of expected hatchlings is multiplied by the discounted terrapin years per hatchlings under baseline conditions.

The terrapin population in the area affected by the spill was estimated to be 4,698 (Michel et. al., 2001). Based on the age-class distribution in Table 3, approximately 28% of the population are fecund (age class eight or older). Using the baseline parameters that 75% of the population is female, each female produces 26 eggs per year, and the egg to hatchling success rate is 20%, the estimated baseline number of hatchlings produced in 2000 is $(4{,}698 * 0.75 * 0.2836 * 26 * 0.2) = 5{,}196.2$. From Table 5, the baseline discounted terrapin years per hatchling is 2.095. The baseline discounted terrapin years for the 2000 hatchling cohort is $5{,}196.2 * 2.095 = 10{,}885.2$.

2. Discounted Terrapin-Years of 2000 Hatchlings under the Effects of Oil

It was assumed that the effect of the oil spill on hatchling success was a 10% reduction in the first-year survivorship, from 41.5% to 37.4%. The expected number of hatchlings is the same as under baseline conditions, 5,196.2. With the reduced first-year survivorship of 37.4%, the discounted terrapin years per hatchling is 1.934, as depicted in Table 7. The estimated discounted terrapin years produced by the 2000 cohort is $5{,}196.2 * 1.934 = 10{,}048.9$.

Table 7: Discounted Terrapin Years per Hatchling in 2000

1	2	3	4
Age	**Annual Surv Rate**	**P(age)**	**DTY per Hatchling**
1	0.374	0.373500	0.666748
2	0.662	0.247257	0.292562
3	0.662	0.163684	0.188035
4	0.862	0.141096	0.135396
5	0.862	0.121625	0.113312
6	0.862	0.104840	0.094830
7	0.847	0.088800	0.078724
8	0.847	0.075213	0.064737
9	0.847	0.063706	0.053235
10	0.847	0.053959	0.043777
11	0.847	0.045703	0.035999
12	0.847	0.038711	0.029603
13	0.847	0.032788	0.024343
14	0.847	0.027771	0.020018
15	0.847	0.023522	0.016462
16	0.847	0.019923	0.013537
17	0.847	0.016875	0.011132
18	0.847	0.014293	0.009154
19	0.847	0.012106	0.007528
20	0.847	0.010254	0.006190
21	0.847	0.008685	0.005090
22	0.847	0.007356	0.004186
23	0.847	0.006231	0.003442
24	0.847	0.005278	0.002831
25	0.847	0.004470	0.002328
26	0.847	0.003786	0.001914
27	0.847	0.003207	0.001574
28	0.847	0.002716	0.001294
29	0.847	0.002301	0.001064
30	0.847	0.001949	0.000875
31	0.847	0.001650	0.000720
32	0.847	0.001398	0.000592
33	0.847	0.001184	0.000487
34	0.847	0.001003	0.000400
35	0.847	0.000849	0.000329
36	0.847	0.000719	0.000271
37	0.847	0.000609	0.000223
38	0.847	0.000516	0.000183
39	0.847	0.000437	0.000151
40	0.847	0.000370	0.000124
41	0.847	0.000314	0.000102
42	0.847	0.000266	0.000084
43	0.847	0.000225	0.000069
44	0.847	0.000191	0.000057
45	0.847	0.000161	0.000047
46	0.847	0.000137	0.000038
47	0.847	0.000116	0.000031
48	0.847	0.000098	0.000026
49	0.847	0.000083	0.000021
50	0.847	0.000070	0.000018
sum			**1.933891**

3. *Lost Discounted Terrapin-Years due to Increased Hatchling Mortality*

The lost discounted terrapin years due to the increased mortality of hatchlings is the difference between the discounted terrapin years provided under baseline conditions and the conditions found during the oil spill. The injury is 10,885.2 – 10,048.9 = 836.3 discounted terrapin years.

III. SUMMARY

Based on the survival rates from the diamondback terrapin and several other species in the emydid family, the average age of the Patuxent River population of diamondback terrapins is estimated to be 6 years. Roosenburg (1990a) stated that the maximum attainable age could be as long as 50 years. Using estimated survival rates and discounting the lost terrapin-years results in an estimated 615.6 of direct discounted terrapin-years lost.

From Table 1, it is expected that a female terrapin will produce 26 eggs per year. Based on survivorship over their lifetime, each hatchling born into a cohort was estimated to contribute 2.095 discounted terrapin-years. Taking account of the survivorship of females and the age of fecundity, the total hatchling discounted terrapin-years lost (adult equivalent) is estimated to equal 3,792.7.

It was assumed that the oil spill caused a 10% reduction in the survivorship of hatchlings for the 2000 nesting season. This effect reduced the discounted terrapin-years for the 2000 cohort to 1.934 from the baseline level of 2.095. This is a loss of 0.161 discounted terrapin years per hatchling. The 2000 hatchling cohort size is estimated to be 5,196. The loss due to increased hatchling mortality is 836.3 discounted terrapin-years.

The sum of the direct terrapin-years lost, production foregone, and the loss from increased hatchling mortality is the total terrapin-years lost for the Chalk Point oil spill event. Based on these calculations, the total injury for the Patuxent River population of diamondback terrapins is estimated to be 5,244.6 discounted terrapin-years (Table 8).

Table 8: Summary of the Lost Discounted Terrapin Years

				Diirect Lost Terrapin Years			*Production Foregone*				*Increased 2000 Hatchling Mortality*				*Total*	
Year After Spill	**Age of Adults**	**Annual Survival Rate**	**P(year)**	**Expected Adults**	**Terrapin Years (Survivors)**	**Terrapin Years (Deceased)**	**Expected Females**	**Expected Hatchlings**	**DTY per Hatchling**	**Terrapin Years (Hatchlings)**	**Expected Hatchlings**	**DTY per Hatchling (Basline)**	**DTY per Hatchling (With Spill)**	**Lost DTY 2000 Hatchlings**	**Terrapin Years (all categories)**	**DTY**
0	6			122			91.5				5,196.232	2.095	1.934	836.278	836.278	836.278
1	7	0.847	0.847	103.334	103.334	9.333	77.501								112.667	109.385
2	8	0.847	0.717	87.524	87.524	7.905	65.643	341.343	2.095	715.056					810.485	763.960
3	9	0.847	0.608	74.133	74.133	6.696	55.600	289.118	2.095	605.652					686.481	628.227
4	10	0.847	0.515	62.790	62.790	5.671	47.093	244.883	2.095	512.988					581.449	516.610
5	11	0.847	0.436	53.183	53.183	4.803	39.888	207.416	2.095	434.501					492.487	424.824
6	12	0.847	0.369	45.046	45.046	4.069	33.785	175.681	2.095	368.022					417.137	349.346
7	13	0.847	0.313	38.154	38.154	3.446	28.616	148.802	2.095	311.715					353.315	287.277
8	14	0.847	0.265	32.317	32.317	2.919	24.238	126.035	2.095	264.022					299.258	236.237
9	15	0.847	0.224	27.372	27.372	2.472	20.529	106.752	2.095	223.627					253.471	194.265
10	16	0.847	0.190	23.184	23.184	2.094	17.388	90.419	2.095	189.412					214.690	159.750
11	17	0.847	0.161	19.637	19.637	1.774	14.728	76.585	2.095	160.432					181.843	131.367
12	18	0.847	0.136	16.633	16.633	1.502	12.474	64.867	2.095	135.886					154.021	108.027
13	19	0.847	0.115	14.088	14.088	1.272	10.566	54.943	2.095	115.095					130.456	88.834
14	20	0.847	0.098	11.932	11.932	1.078	8.949	46.536	2.095	97.486					110.496	73.051
15	21	0.847	0.083	10.107	10.107	0.913	7.580	39.416	2.095	82.570					93.590	60.072
16	22	0.847	0.070	8.560	8.560	0.773	6.420	33.386	2.095	69.937					79.271	49.399
17	23	0.847	0.059	7.251	7.251	0.655	5.438	28.278	2.095	59.237					67.142	40.622
18	24	0.847	0.050	6.141	6.141	0.555	4.606	23.951	2.095	50.174					56.870	33.405
19	25	0.847	0.043	5.202	5.202	0.470	3.901	20.287	2.095	42.497					48.168	27.470
20	26	0.847	0.036	4.406	4.406	0.398	3.304	17.183	2.095	35.995					40.799	22.589
21	27	0.847	0.031	3.732	3.732	0.337	2.799	14.554	2.095	30.488					34.557	18.576
22	28	0.847	0.026	3.161	3.161	0.285	2.371	12.327	2.095	25.823					29.269	15.275
23	29	0.847	0.022	2.677	2.677	0.242	2.008	10.441	2.095	21.872					24.791	12.561
24	30	0.847	0.019	2.268	2.268	0.205	1.701	8.844	2.095	18.526					20.998	10.330
25	31	0.847	0.016	1.921	1.921	0.173	1.440	7.490	2.095	15.691					17.785	8.494
26	32	0.847	0.013	1.627	1.627	0.147	1.220	6.344	2.095	13.291					15.064	6.985
27	33	0.847	0.011	1.378	1.378	0.124	1.033	5.374	2.095	11.257					12.759	5.744
28	34	0.847	0.010	1.167	1.167	0.105	0.875	4.552	2.095	9.535					10.807	4.724
29	35	0.847	0.008	0.989	0.989	0.089	0.741	3.855	2.095	8.076					9.154	3.884
30	36	0.847	0.007	0.837	0.837	0.076	0.628	3.265	2.095	6.840					7.753	3.194
31	37	0.847	0.006	0.709	0.709	0.064	0.532	2.766	2.095	5.794					6.567	2.627
32	38	0.847	0.005	0.601	0.601	0.054	0.450	2.343	2.095	4.907					5.562	2.160
33	39	0.847	0.004	0.509	0.509	0.046	0.382	1.984	2.095	4.156					4.711	1.776
34	40	0.847	0.004	0.431	0.431	0.039	0.323	1.681	2.095	3.521					3.990	1.461
35	41	0.847	0.003	0.365	0.365	0.033	0.274	1.423	2.095	2.982					3.380	1.201
36	42	0.847	0.003	0.309	0.309	0.028	0.232	1.206	2.095	2.526					2.863	0.988
37	43	0.847	0.002	0.262	0.262	0.024	0.196	1.021	2.095	2.139					2.425	0.812
38	44	0.847	0.002	0.222	0.222	0.020	0.166	0.865	2.095	1.812					2.054	0.668
39	45	0.847	0.002	0.188	0.188	0.017	0.141	0.733	2.095	1.535					1.740	0.549
40	46	0.847	0.001	0.159	0.159	0.014	0.119	0.621	2.095	1.300					1.473	0.452
41	47	0.847	0.001	0.135	0.135	0.012	0.101	0.526	2.095	1.101					1.248	0.371
42	48	0.847	0.001	0.114	0.114	0.010	0.086	0.445	2.095	0.933					1.057	0.305
43	49	0.847	0.001	0.097	0.097	0.009	0.073	0.377	2.095	0.790					0.895	0.251
44	50	0.847	0.001	0.082	0.082	0.007	0.061	0.319	2.095	0.669					0.758	0.207
sum																**5244.591**

References

Bishop, J. M. 1983. Incidental capture of diamondback terrapins by crap pots. Estuaries: Vol. 6: 426-430.

Heppell, S.S. 1998. Application of life-history theory and population model analysis to turtle conservation. Copeia. Vol. 2: 367-375.

Michel, J., R. Greer, M. Hoffman, P. McGowan, and R. Wood. 2001. Acute Mortality of Diamondback Terrapins from the Chalk Point Oil Spill. Report by the Wildlife Injury Workgroup to the Chalk Point Oil Spill Natural Resource Trustee Council. October, 2001, 7 pp.

Mitchell, J.C. 1988. Population ecology and life histories of the freshwater turtles Chrysemys picta and Sternotherus odoratus in an urban lake. Herp. Monogr. 2: 40-61.

NatureServe: An online encyclopedia of life [web application]. 2001. Version 1.4. Arlington, Virginia, USA: Association for Biodiversity Information. Available at: http://www.natureserve.org/. (Accessed: July 9, 2001).

Roosenburg, W.M. 1990a. The diamondback terrapin: population dynamics, habitat requirements, opportunities for conservation. In Proceedings of a Conference: New Perspectives in the Chesapeake System: A Research and Management Partnership. Baltimore, Maryland. Pages 227-234.

Roosenburg, W.M. 1990b. Final Report: Chesapeake diamondback terrapin investigations for the period 1987, 1988, and 1989. Chesapeake Research Consortium. Solomons, Maryland. 84pp.

Roosenburg, W.M. 1992. Life history consequences of nest site choice by the diamondback terrapin, malaclemys terrapin. UMI Dissertation Services. Ann Arbor, Michigan. 206pp.

Sperduto, M., C. Hebert, M. Donlan, and S. Thompson. 1999. (unpublished report) Injury quantification and restoration scaling for marine birds killed as a result of the *North Cape* oil spill. U.S. Fish and Wildlife Service. 32pp.

Tinkle, D.W. , J.D. Congdon and P.C. Rosen. 1981. Nesting frequency and success: implications for the demography of painted turtles. Ecology 62: 1426-1432.

Wilbur, H.M. 1975. The evolutionary and mathematical demography of the turtle Chrysemys picta. Ecology 56: 64-77.

Wood, R. and S. Hales, Personal Communication, 2000-2002. Multiple conversations with diamondback terrapin experts from the Wetlands Institute, Stockton State College, New Jersey, regarding the life history of terrapins and the potential impacts of oil.

Wood, R. and S. Hales. 2001. Comparison of northern diamondback terrapin (*Malaclemys terrapin terrapin*) hatching success among variably oiled nesting sites along the Patuxent River following the Chalk Point Oil Spill of April 7, 2000.

November 11, 2001

Norman Meade
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Dear Norman:

The following are my combined comments on two reports, "Acute Mortality of Diamondback Terrapins from the Chalk Point Oil Spill" and "Estimate of Total Injury to Diamondback Terrapins from the Chalk Point Oil Spill." Both reports address the quantification of natural resource injury to terrapins under the 1990 Oil Pollution Act (OPA) following the April 2000 Chalk Point oil spill in the Patuxent River.

The purpose of the Acute Mortality study was to estimate the direct mortality to diamondback terrapins (*Malaclemys terrapin*) from the oil spill. The goal of the Total Injury report was to estimate the number of lost diamondback terrapin years, based on both acute mortality and the loss of production of the next generation, following the oil spill. My review of these reports addresses the following queries:

1. Were the assumptions used and the data and methods employed by the investigators appropriate for undertaking the stated goals of the study?

2. Were the methods employed properly implemented?

3. Do you have suggestions on how to improve the substance and exposition of the report?

General Statement:

My overall assessment of the two reports is that a fair treatment of the situation was given considering the absence of thorough knowledge of the disposition of terrapins throughout the system and the limited data that were available. In essence, as good a job as possible was done with the material available, and the approach used of building scenarios based on known biological facts was reasonable and appropriate. To the best of my knowledge the model quantifying total lost terrapin years has been properly implemented. A few specific points bear mentioning.

Specific Comments

Acute Mortality Study

Table 1 – The authors need to be consistent in use of "pipeline break marsh" – if this is a specific locality it should be capitalized; need to clarify "notched" on April 30 – does this mean a marked animal from a study or an animal injured by a boat?

page 2 – The point about increased boat traffic is a good one that should be included in the final report, as such activities are a consequence of the spill.

page 3 – The last sentence in first paragraph under Mortality Estimates needs to provide confidence limits (range) for the total population estimate.

page 3 – The most difficult assumption in the acute injury report is the 10%, 2%, and 0.5% estimates of mortality. My suggestion is that these be referred to as professional opinions based on limited availability of data. The rationale for such an estimate is that higher proportions would not be expected because of the minimal number of oiled or dead terrapins found after the spill. However, the finding of several individuals affected by the oil spill suggests that at least a small proportion of the population was affected, which would presumably be reduced in habitats receiving lesser amounts of oil.

Total Injury Study

Table 1 – This table needs to be partitioned into two parts (1. Population parameters and 2. Parameter values) in order to keep the columns clear and consistent.

Table 2 -- The citations need to be provided for Wilbur 1975, Tinkle et al. 1981, and Mitchell 1988. Defining values as both the "mean" and the "average" is confusing as the numbers should be the same for either.

page 5 - The series of assumptions are tedious to follow but seem to be best estimates that are accurate within the context of available data on the species for the Patuxent River area.

page 11 - In the Summary, the maximum of "39 eggs per year" is used in the final calculation. In other parts of the reports, both the mean and range have been given. Explanation should be given for why the maximum is being used for the potential number of eggs.

I hope these comments are useful. Please let me know if you need additional information.

Sincerely,

J. Whitfield Gibbons
Professor of Ecology

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