Management and Conservation Article

Recovery of the Chesapeake Bay Bald Eagle Nesting Population

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ABSTRACT We conducted annual aerial surveys throughout the tidal reach of the Chesapeake Bay, USA, between 1977 and 2001 to estimate population size and reproductive performance for bald eagles (*Haliaeetus leucocephalus*). The population increased exponentially from 73 to 601 pairs with an average doubling time of 8.2 years. Annual population increase was highly variable and exhibited no indication of any systematic decline. A total of 7,590 chicks were produced from 5,685 breeding attempts during this period. The population has exhibited tremendous forward momentum such that >50% of young produced over the 25-year period were produced in the last 6 years. Rapid population growth may reflect the combined benefits of eliminating persistent biocides and active territory management. Reproductive rate along with associated success rate and average brood size increased throughout the study period. Average reproductive rate (chicks/breeding attempt) increased from 0.82 during the first 5 years of the survey to 1.50 during the last 5 years. Average success rate increased from 54.4% to >80.0% during the same time periods. The overall population will likely reach saturation within the next decade. The availability of undeveloped waterfront property has become the dominant limiting factor for bald eagles in the Chesapeake Bay. Maintaining the eagle population in the face of a rapidly expanding human population will continue to be the greatest challenge faced by wildlife biologists. (JOURNAL OF WILDLIFE MANAGEMENT 72(1):152–158; 2008)

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Since the ban on DDT and like compounds in 1972, bald eagle (*Haliaeetus leucocephalus*) populations have exhibited dramatic growth throughout their breeding range. Bald eagles throughout the conterminous United States have increased from an estimated low in 1963 of 417 pairs (Sprunt 1963) to an estimated 5,748 pairs by 1998 (Millar 1999). This represents an average annual increase of nearly 8% despite the fact that some populations did not show appreciable growth until the early 1980s (Buehler 2000). In response to the dramatic increases in population size, productivity, and distribution, the bald eagle was reclassified from endangered to threatened in 1995 by the United States Fish and Wildlife Service (Millar 1995) and was proposed for removal from the federal list of threatened and endangered species in 1999 (Millar 1999).

The Chesapeake Bay area, USA, was 1 of 5 regions established in the mid-1970s for the recovery of the bald eagle. Biologists within the Bay have had a long history of work with eagles since the first ground survey was conducted in 1936 (Tyrell 1936). There was an estimated 600–800 nesting pairs in the 1930s. Surveys have been conducted annually for >45 years beginning with ground surveys in 1956 (Abbott 1957) and continuing with aerial surveys since 1962 (Abbott 1963, 1976; Sprunt 1963). By 1962 the nesting bald eagle population had declined to 150 pairs with a productivity rate of only 0.2 young per active nest. By 1970 there were only 80–90 pairs in the Chesapeake Bay area.

In 1977 the United States Fish and Wildlife Service formed the Chesapeake Bay Bald Eagle Recovery Team (Abbott 1977). This team was tasked with developing a plan for the recovery of the Bay population. As part of this process, state wildlife agencies assumed the responsibility for population monitoring. The 2001 breeding season represented the 25th year of the comprehensive bald eagle breeding survey under the coordination of the respective state agencies. The purpose of this paper is to present the results of this 25-year period and to discuss findings with respect to regional recovery goals and the future of the population.

STUDY AREA

Our study area included the entire tidal reach of the Chesapeake Bay (Fig. 1). The Chesapeake Bay is the largest estuary in the United States, containing >19,000 km of tidal shoreline. The Bay's wide salinity gradient, shallow water, and climate have made it one of the most productive aquatic ecosystems in North America. Bald eagles breed throughout the estuary from the Atlantic Ocean to the fall line. The fall line is an erosional scarp where the metamorphic rocks of the Piedmont meet the sedimentary rocks of the Coastal Plain. The geologic formations along this boundary frequently determine the landward extent of tidal influence. Forest cover has varied dramatically since European settlement, reaching a low of 50% in the late 1800s, but is now the dominant land cover except in areas with intensive agriculture (Brush 2001). Forest composition forms a pine–hardwood gradient throughout the Bay with pine-dominated forests on the outer Coastal Plain to hardwood-dominated forests on the inner Coastal Plain. Pine forests are dominated by loblolly pine (*Pinus taeda*) and mixed hardwoods are dominated by various oaks (*Quercus* spp.), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), and tulip poplar (*Liriodendron tulipifera*). The Bay supports a diverse fish community that has been the

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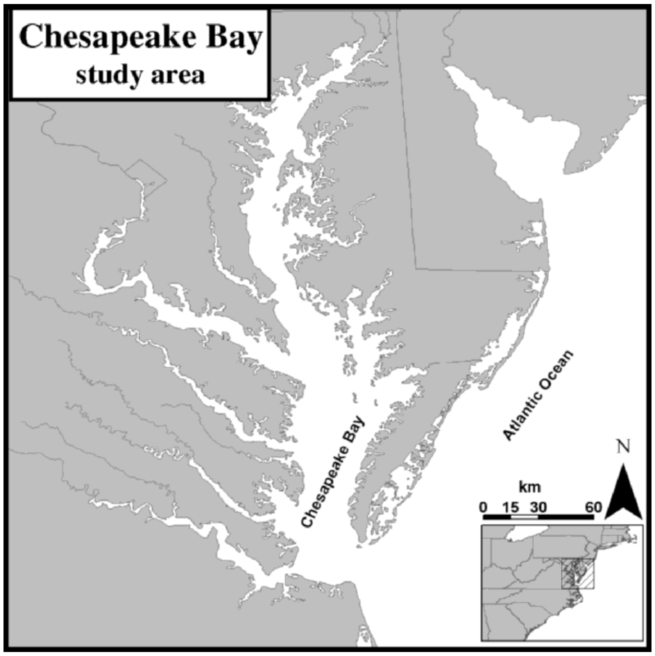

Figure 1. We surveyed bald eagles within the Chesapeake Bay, USA (1977–2001). We did not include areas outside of the tidal reach of the Bay watershed in this study.

basis of significant commercial fisheries (Murdy et al. 1997). The Chesapeake Bay and its adjacent uplands are under increasing pressure for growth and development. The human population within counties adjacent to the tidal reach of the Bay has increased from 1.63 million people in 1900 to 3.81 million people in 1950 to 8.06 million people in 2000 (http://www.census.gov). This growth is expected to continue into the foreseeable future (Gray et al. 1988), placing increasing pressures on the Bay and its natural resources.

METHODS

We have systematically surveyed the entire study area for breeding bald eagles since spring 1977 via a standard 2-flight approach (Fraser et al. 1983). We conducted the first flights between late February and the end of March to locate breeding territories. We used a Cessna 172 or 180 aircraft to systematically over-fly the land surface at an altitude of approximately 100 m to detect eagles and nests. We maneuvered the aircraft between the shoreline and a distance of 1–3 km to cover the most probable breeding locations. Survey effort and coverage was consistent throughout the study period. We plotted nests detected on 7.5-minute topographic maps and gave them unique alpha-numeric codes. We examined each nest to determine its condition and status. We considered a breeding territory to be occupied if we observed a pair of birds in association with the nest and there was evidence of recent nest maintenance (e.g., well-formed cup, fresh lining, structural maintenance). We considered nests to be active if we observed a bird in an incubating posture or if we detected eggs or young in the nest (Postupalsky 1974). We conducted the second survey flights from late April through May to check occupied nests for productivity and to recheck occupied territories for breeding. We flew a plane low over the nest, allowing observers to examine nest contents and record the number of eaglets.

Previous authors (e.g., Fraser 1978, Steenhof and Kochert 1982, Fraser et al. 1984, Steenhof 1987) have outlined several potential sources of bias inherent in the 2-flight survey for raptor populations. One such source arises from pairs that make breeding attempts, but fail prior to the first survey flight. This bias serves to both underestimate the nesting population and inflate the per capita reproductive rate. In this study, we used the number of territories determined to be occupied rather than the number of nests with eggs to represent the breeding population. Although this parameter is subject to similar concerns, we feel that it is more robust with respect to this source of sampling error. A second source of error stems from using a single productivity flight within an asynchronous population. When used alone, a single survey records chicks from a cross-section of ages and assumes no mortality. The error associated with this assumption serves to overestimate fledging success since some young chicks do not to survive to fledging age. We have not corrected for this source of error.

We defined breeding success as the percentage of occupied nests that contained $\geq$1 young, reproductive rate as the number of young per occupied nest, and average brood size as the number of young per successful nest. We expressed population growth rate using the average time (in yr) required for the population to double in size (t_{double}), the intrinsic rate of increase (r), and the average annual percent increase over the study period. We calculated average doubling time using the growth equation $N_t = N_0 e^{rt}$ where N_t is the population size in 2001, N_0 is the population size in 1977, e is the base of the natural logarithm, r is the intrinsic rate of increase, and t is the time interval between population estimates. With this configuration, $t_{\text{double}} = \ln(2)/r$. We calculated average annual percent increase as $(N_{t+1} - N_t)/N_t \times 100$.

RESULTS

Between 1977 and 2001, the bald eagle breeding population in the tidal reach of the Chesapeake Bay increased from 73 pairs to 601 pairs (Table 1). During this period, the population grew exponentially with an average doubling time of 8.2 years. Intrinsic rate of increase (r) was 0.084. Average annual increase was 9.4 ± 1.11% ($\bar{x}$ ± SE). The annual population increase, as expressed by a percentage, was highly variable over the study period and ranged from a low of 2.2% (1998–1999) to a high of 22.0% (1989–1990). There is no indication over the survey period that this rate has shown any directional change ($R^2 = 0.045$, $F[1,22] = 1.034$, $P = 0.429$).

During the study period, we documented 5,685 breeding attempts that produced 7,590 young (Table 1). Average, annualized rates were 70.7 ± 2.12%, 1.19 ± 0.554, and 1.7 ± 0.03 for breeding success, reproductive rate, and brood size, respectively. The population has exhibited tremendous

Table 1. Bald eagle population size and productivity within the tidal reach of the Chesapeake Bay, USA (1977–2001).

Yr	Occupied nests	Active nests	Successful nests	Young	Successful/ occupied[a]	Successful/ active[a]	Young/ occupied[a]	Young/ active[a]	Young/ successful[a]
1977	73	69	39	62	53.4	56.5	0.8	0.9	1.6
1978	83	79	40	55	48.2	50.6	0.7	0.7	1.4
1979	87	82	38	57	43.7	46.3	0.7	0.7	1.5
1980	90	82	47	68	52.2	57.3	0.8	0.8	1.4
1981	93	88	54	89	58.1	61.4	1.0	1.0	1.6
1982	105	101	61	94	58.1	60.4	0.9	0.9	1.5
1983	112	106	69	109	61.6	65.1	1.0	1.0	1.6
1984	120	114	73	124	60.8	64.0	1.0	0.9	1.7
1985	125	122	86	158	68.8	70.5	1.3	1.0	1.8
1986	131	127	95	179	72.5	74.8	1.4	1.1	1.9
1987	154	152	123	221	79.9	80.9	1.4	1.3	1.8
1988	171	169	137	247	80.1	81.1	1.4	1.4	1.8
1989	182	179	122	200	67.0	68.2	1.1	1.5	1.6
1990	222	212	161[b]	298	74.2	77.8	1.4	1.5	1.9
1991	232	224	179	313	77.2	79.9	1.3	1.1	1.7
1992	274	267	189[b]	317	69.2	71.1	1.2	1.4	1.7
1993	287	280	194	331	67.6	69.3	1.2	1.4	1.7
1994	307	276	193[b]	337	63.1	70.2	1.1	1.2	1.7
1995	340	307	250[b]	464	74.4	82.5	1.4	1.2	1.9
1996	377	348	267[b]	490	72.8	79.0	1.3	1.2	1.8
1997	416	387	294[b]	557	72.4	78.0	1.4	1.5	1.9
1998	462	415	318[b]	563	70.0	78.1	1.2	1.4	1.8
1999	472	441	348[b]	650	75.3	80.7	1.4	1.5	1.9
2000	513	487	402[b]	758	79.3	83.6	1.5	1.6	1.9
2001	601	571	448[b]	849	75.7	79.7	1.4	1.5	1.9

[a] Based on nests with known outcome.

[b] Final outcome of <10 nests not determined and not included in totals.

forward momentum such that >50% of young produced over the 25-year period have been produced in the 6 years since 1995.

Per capita reproductive rates increased significantly over the study period ($R^2 = 0.72$, $F[1,23] = 58.4$, $P < 0.001$; Fig. 2). Reproductive rates averaged 0.82 ± 0.058 for the period 1977 to 1981 compared to 1.50 ± 0.032 for the period 1997 to 2001. The specific form of this increase may not be simple linear. It appears that reproduction has shown a general increase since the 1970s, but also experienced a perturbation in the early 1990s (Fig. 2). The overall increase in per capita reproductive rate resulted from a significant increase in both success rate ($R^2 = 0.69$, $F[1,23] = 50.7$, $P < 0.001$) and average brood size ($R^2 = 0.60$, $F[1,23] = 33.8$, $P < 0.001$). Average success rate increased from 54.4% for the period 1977 to 1981 to >80% for the period 1997 to 2001. Success rate and average brood size are strongly and positively correlated ([Spearman Rank correlation coeff.] $r_s = 0.837$, $P < 0.001$; Fig. 3), suggesting that reproduction is regulated by some factor that varies annually throughout the entire Bay.

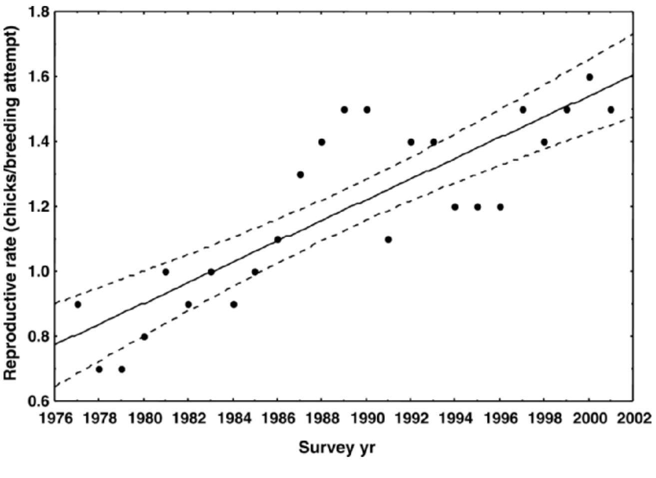

Figure 2. Relationship between reproductive rate (chicks/active nest) and year for bald eagles within the tidal reach of the Chesapeake Bay, USA (1977–2001).

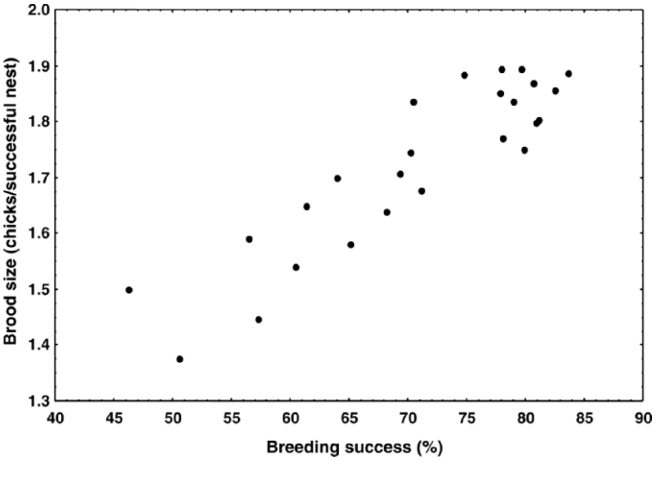

Figure 3. Relationship between average brood size and breeding success for bald eagles within the tidal reach of the Chesapeake Bay, USA (1977–2001).

DISCUSSION

The Chesapeake Bay bald eagle population has now recovered to the size estimated during the 1930s (Tyrell 1936, Abbott 1978). Population size thresholds outlined in the Chesapeake Bay Bald Eagle Recovery Plan (Byrd et al. 1990) for federal downlisting (175–200) and delisting (300–400) were met in 1988 and 1992, respectively, for the broader Chesapeake Bay Recovery Region (Millar 1995, 1999). The recovery region extends well beyond the tributaries of the Chesapeake Bay and includes all of Virginia, Maryland, Delaware, and New Jersey, as well as portions of Pennsylvania and West Virginia, USA (Byrd et al. 1990). Our study area typically supports 90–95% of the population within the broader recovery region.

We documented an average annual rate of increase of 9.4%. Buehler et al. (1991*a*) used demographic data along with a deterministic life-table model to predict population growth for the Chesapeake Bay population. They estimated minimum and maximum survival rates based on 39 eagles that were monitored with telemetry and predicted a range of population growth rates from 5.8% to 16.6% per year. These predictions are in general agreement with the observed growth rate of 9.4% reported here. Sensitivity analysis revealed that model estimates were most sensitive to changes in adult survivorship followed by subadult survivorship. As expected, growth rates were relatively robust against variation in nest success and reproductive rates.

Nesting success in the Chesapeake Bay may be the highest on record in North America. Since 1995, ≥70% of occupied territories produced ≥1 young. Success rates in many parts of North America have ranged between 60% and 65%, including the Pacific Northwest (Anthony et al. 1994, Watson et al. 2002) and the Rocky Mountains (Swenson et al. 1986, Kralovec et al. 1992). In Alaska (Stiedl et al. 1997) and Arizona, USA (Driscoll et al. 1999) only half of nesting pairs produced young.

The reproductive rate of Chesapeake Bay eagles is comparable to or greater than those of other regions. The highest reproductive rates have been in Florida, USA, where nesting bald eagles produced 1.3 young per breeding pair during 1997–2001 (Millsap et al. 2004) and Wisconsin, USA, where eagles produced 1.3 young per occupied territory in the mid 1980s (Kozie and Anderson 1991). Productivity in the Rocky Mountain states has ranged from 1.0 to 1.2 young per nesting pair (Swenson et al. 1986, Kralovec et al. 1992). Reproductive rates in the Pacific Northwest were 0.9 young per occupied nest (Anthony et al. 1994, Watson et al. 2002). In Alaska, productivity (0.8 young/pair) was well below that in the Chesapeake Bay (Stiedl et al. 1997). The lowest reproductive rate (0.13 young/pair) recorded in recent times was in Alaska on Prince of Wales Island (Anthony 2001). That low rate was attributed to high densities of nesting bald eagles. There is no indication in the Chesapeake Bay that nesting densities are reducing productivity rates yet.

A reproductive rate of 0.7 chicks per breeding attempt has been suggested to represent the threshold for population maintenance for bald eagles (Sprunt et al. 1973). Buehler et al. (1991*a*) estimated that 1.0 chicks per successful nest (equivalent to brood size) was required for population maintenance in the Bay. A reproductive rate of 1.1 chicks per breeding attempt was set as the recovery goal for the Chesapeake Bay population (Byrd et al. 1990). Documented rates for the Chesapeake Bay population reached an all-time low of 0.2 chicks per breeding attempt in 1962 (Abbott 1963). Productivity showed a steady increase throughout the late 1960s and early 1970s, reaching projected maintenance levels by the mid-1970s (Abbott 1978). The population has met or exceeded the productivity target outlined in the recovery plan in every year since 1985. The reproductive rate documented by Tyrrell in 1936 was nearly 1.5 chicks per breeding attempt. The population has achieved this rate in 4 of the 5 years between 1997 and 2001.

We documented an increase in reproductive rates throughout the period of this study. This increase resulted from increases in both elements of reproduction including the proportion of nesting attempts that were successful and average brood size for successful nests. Gains in the early portion of the study likely reflect the general recovery in productivity that followed a reduction in contaminant use within the Bay. The concentrations of DDE, dieldrin, and PCBs in eggs from the Chesapeake Bay during 1973–1979 were among the highest for any bald eagle population in the United States (Wiemeyer et al. 1984). However, dramatic reductions in these contaminants were documented by the mid-1980s (Wiemeyer et al. 1993). This time frame corresponds to a time when many of the breeding populations throughout the lower portion of the breeding range began to show definitive signs of growth (Buehler 2000). Why reproductive rates have continued to rise after the mid-1980s is less clear. It is possible that recent gains reflect a continued lag in productivity as older adults with higher contaminant loads in the population are replaced or that some other demographic process is at work.

We documented a strong, positive correlation between annual success rate and average brood size throughout the Chesapeake Bay. This relationship shows that during good years a larger portion of pairs are productive and that productive pairs raised larger broods compared to poor years. This pattern implies that annual variation in reproductive rates may, at least in part, be regulated by factors that are acting on a large geographic scale. While reproductive rates in bald eagles are certainly responsive to spatial and temporal variation in prey resources (e.g., Hansen 1987, Bortolotti 1989, Steidl et al. 1997), it is not likely that prey stocks alone are responsible for this specific pattern. Fish are the dominant prey used by bald eagles for brood-rearing in the Chesapeake Bay (Wallin 1982, Markham 2004). The Chesapeake Bay supports a diverse fish assemblage, but interspecific synchrony in stocks is poor and intraspecific cycles in stocks often vary tributary to tributary (Murdy et al. 1997). Annual variation in spring weather conditions throughout the Bay may be a more likely explanation for this pattern. A relationship between weather and productivity has been suggested for other eagle populations (e.g., Isaacs et al. 1983, Swenson et al. 1986). Wet conditions throughout the spring have been suggested to influence brood provisioning, growth rates, and reproductive success in the lower Bay (Markham 2004). Extended periods of rain both increase the exposure of broods and make hunting more difficult. Depending on brood age, these factors may result in brood reduction or failure.

Given the tremendous forward momentum currently exhibited by the breeding population, it seems likely that bald eagles will reach saturation within the Bay in a relatively short period of time. No specific estimates of the Chesapeake Bay bald eagle population are available prior to the early 1900s. However, given the high productivity of Bay waters and the availability of extensive shallow-water foraging areas, it has been speculated that prior to European settlement the Chesapeake Bay may have supported one of the densest breeding populations of bald eagles outside of Alaska. By applying breeding densities from Alaska to the 13,000 km of Chesapeake shoreline, Fraser et al. (1996) suggested that the Chesapeake may have supported in excess of 3,000 breeding pairs of bald eagles prior to European Settlement. However, a recent investigation shows significant spatial variation in both colonization rates and breeding density, suggesting that carrying capacity varies widely throughout the Bay (Watts et al. 2006). By fitting population growth data (1977–2002) for birds in portions of the lower Chesapeake Bay to a logistic curve, Watts et al. (2006) estimated that the population had reached approximately 70% of capacity. This suggests that the current carrying capacity of the Bay may be half of that estimated by Fraser et al. (1996) for the pristine Bay and that if recent growth rates continue, this population should reach that level within the next decade.

The availability of undeveloped waterfront property has become the dominant limiting factor for bald eagles in the Chesapeake Bay. Human activity is the best predictor of eagle distribution within the tidal portion of the Bay. Indicators of human activity such as housing and road density, shoreline use, and boating activity have been related to nest distribution (Watts et al. 1994), shoreline use (Buehler et al. 1991*b*, Watts and Whelan 1997), and the likelihood of nest abandonment (Therres et al. 1993) or recolonization (B. D. Watts, College of William and Mary, unpublished data). Since bald eagles began their most dramatic decline in the 1950s, the human population within the tidal reach of the Bay has increased by >50% (http://www.census.gov). A preliminary review of development occurring around eagle nests in the lower Chesapeake Bay shows that development had occurred in 55% of shoreline areas by the late 1980s (Byrd et al. 1990). Similarly, Buehler et al. (1991*b*) found that in northern areas of the Bay, 75.6% of the shoreline had developments within 500 m. Application of a habitat suitability model to the James River in 1991 revealed that >50% of the available area was not suitable for eagle breeding due to human use (Watts et al. 1994).

Increases in the human population around the Chesapeake Bay are expected to continue for the foreseeable future (Gray et al. 1988), likely causing further reductions in the capacity of the Bay to support bald eagles. In the long term, the size and stability of the breeding population will depend on both the bald eagle's capacity to cope with human activity and the management community's ability to protect suitable breeding habitat. In Florida, Millsap et al. (2004) found similar nest-occupancy rates and brood sizes between suburban and rural nesting bald eagles. They defined suburban nest sites as those with >50% intensive human use within 1,500 m of the nest. Young per occupied nest site averaged 1.3 in suburban nests between 1996 and 2001. That is comparable to productivity of Chesapeake Bay bald eagles during the same time period. Though few in number as of 2001, bald eagles nesting in suburban situations are increasing in the Chesapeake Bay area. Over the past decade, the transition in the eagle population has been ongoing with an increasing number of pairs breeding in very disturbed settings. A recent investigation within the lower Chesapeake Bay has shown that success rate and productivity for pairs within the most human-dominated settings are not statistically distinguishable from pairs in the most pristine settings (Watts 2006).

MANAGEMENT IMPLICATIONS

Banning of DDT and the application of management guidelines by state and federal resource agencies have resulted in a dramatic recovery of bald eagles in the Chesapeake Bay. Despite successes, the eagle population continues to be threatened by urban sprawl and associated habitat loss. To date, the management community has not been able to reach 50% of the habitat protection goal set in the Chesapeake Bay Bald Eagle Recovery Plan (Byrd et al. 1990). Based on the current rate of land protection, the increase in the human population, and the proximity of the eagle population to capacity it appears unlikely that this goal will ever be achieved, implying that the future of the population will continue to depend on privately owned lands. Broad land-use efforts, such as Maryland's Chesapeake Bay Critical Area Program (Therres et al. 1988), designed to help control shoreline development may be critical in sustaining the population. Given the current rate of land development along the shores of the Chesapeake Bay, continued population and productivity monitoring is needed to assess how bald eagles respond to habitat changes.

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