CONSERVATION OF THE GOLDEN EAGLE (*AQUILA CHRYSAETOS*) IN THE EUROPEAN ALPS—A COMBINATION OF EDUCATION, COOPERATION, AND MODERN TECHNIQUES

Ulrich M. Brendel, Rolf Eberhardt, and Karen Wiesmann

Berchtesgaden National Park, Doktorberg 6, 83471 Berchtesgaden, Germany

Abstract.—At the beginning of the 20th century, the Golden Eagle (*Aquila chrysaetos*) was close to extinction in many parts of the European Alps. At the end of the century, the population has stabilized at around 1100 breeding pairs. To maintain the population, management strategies have been derived from models of habitat quality and distribution within the eagle's entire alpine range. These models were validated using a variety of data sources. They indicate that there are significant "hot spots" in distribution in the European Alps. Conclusions concerning the habitat quality of particular areas were derived by combining the models with data on human influences on alpine ecosystems, using a Geographic Information System (GIS). Scenarios to estimate the potential impact of future human activities on the breeding success and distribution patterns of the Golden Eagle were calculated from these models. The importance of the Golden Eagle as an environmental indicator for areas of open land in the Alps is considered for future conservation activities. The most effective way to ensure a viable population of Golden Eagles in the European Alps will be to enlist the close cooperation of conservationists and land users, as well as intensive environmental education and user-specific public relation activities.

Key Words: *Golden Eagle*; Aquila chrysaetos; *conservation*; *management*; *European Alps*; *habitat quality models*; *environmental education.*

Conservacion del águila real (*Aquila chrysaetos*) en los Alpes Europeos—una combinacion de educacion, cooperacion, y tecnicas modernas

Resúmen.—A principios del siglo 20, el águila real (*Aquila chrysaetos*) estuvo cerca de la extinción en muchas partes de los Alpes Europeos. Al final del siglo, la población se ha estabilizado alrededor de 1100 parejas reproductivas. Para mantener la población, las estrategias de manejo han derivado de modelos de calidad de hábitat y distribución dentro de todo el rango alpino del águila. Estos modelos fueron validados usando una variedad de fuentes de datos. Ellos indican que hay unos "puntos calientes" significativos en distribución en los Alpes Europeos. Las conclusiones concernientes a la calidad de hábitat de áreas particulares fueron derivadas combinando los modelos con datos sobre la influencia humana en los ecosistemas alpinos, usando un Sistema de Información Geográfica (SIG). Los escenarios para estimar el impacto potencial de futuras actividades humanas en el éxito reproductivo y los patrones de distribución del águila real fueron calculados a partir de estos modelos. La importancia del águila real como un indicador ambiental para áreas abiertas en los Alpes es considerada para futuras actividades en conservación. La mas efectiva manera de asegurar una población viable de águilas reales en los Alpes Europeos será enlistar la estrecha cooperación de los conservacionistas y los usuarios de las tierras, al igual que una educación ambiental intensiva y actividades de relaciones publicas usuario-especificas.

[Traducción de César Márquez y Victor Vanegas]

After a severe decline at the end of the 19th and the beginning of the 20th centuries, the Golden Eagle (*Aquila chrysaetos*) population in the European Alps is now estimated at about 1100 breeding pairs (Brendel 1998) and almost all suitable habitats appear to be occupied (Brendel et al. 2000). The population appears to be regulated through intraspecific competition in many parts of its alpine range (Jenny 1992). However, human-related changes in hunting areas used by Golden Eagles, especially in open land areas and alpine pastures above and below timberline, and disturbances within 300 m of nesting sites could alter the current status of the Golden Eagle population (Brendel et al. 2000).

Almost 500 million tourists visit the European Alps each year (Siegrist 1998) and this number is increasing, as is activity of helicopters and paragliders. Therefore, long-term conservation and management measures must be developed to avoid future declines in the eagle population caused by changes in its hunting habitats and disturbances at its nest sites (Brendel and d'Oleire-Oltmanns 1996). An environmental education program, involving close cooperation with user groups such as paragliders, has shown to be the most successful way to establish local conservation strategies and change human behavior. This could also provide a better understanding of eagles and their ecological needs in order to improve the acceptance of management recommendations (Brendel et al. 2000).

STUDY AREA

The geomorphological structure of the Alps is very heterogeneous, making it difficult to study the habitat preferences and population density of Golden Eagles in the area. For this reason, it was necessary to choose a study area with excellent digital data in order to develop general models on habitat preference and density which can then be validated by using long-term observational data and finally extrapolated to larger areas. The Berchtesgaden National Park (210 km²) is located in the southeastern part of Germany within the Berchtesgaden Biosphere Reserve (460 km²), close to the border of Austria. It represents a comparatively small part of the "northern limestone Alps" as well as the northern limit of the distribution of Golden Eagles within the European Alps (total area 200 000 km²).

METHODS

Geographic Information System. Habitats of animals and their relationships toward each other have been investigated in the Berchtesgaden National Park for over 15 yr using a Geographic Information System (GIS). The GIS utilizes more than 150 landcover types derived from interpretation of color infrared (CIR) photos, and provides a detailed digital database of habitats within the study area. In addition, the GIS incorporates a digital elevation model based upon 20 m increments between 500–2750 m.

Modeling. Models concerning habitat quality and potential settlement density were derived from published ecological data on Golden Eagles (Glutz v. Blotzheim 1971, Jenny 1992, Bezzel 1976, Bezzel and Fünfstück 1994, Zechner 1995, Haller 1996, Watson 1997) to identify the most important habitats and actual areas of concentration or distributional "hot spots." Data were interpreted using ARC/INFO (Eberhardt 1996) for the area of the Berchtesgaden Biosphere Reserve (BR).

To predict habitat preferences of eagles in the study area, the most important factors were aggregated within three parameter classes: flight conditions (thermal + slope updrafts), prey abundance (active prey + carrion), and permanent human disturbances (e.g., roads, trails, and cable railways). These parameters were evaluated and then integrated into the final model (Eberhardt 1996). To provide evidence of spatial preferences, it was necessary to consider localized relationships between areas of different suitability classes (e.g., if a small area with high habitat quality is surrounded by many others of low habitat quality, that particular area will probably be avoided because of high energetic costs for the species). We used the "Kernel-HSI-Procedure" (Eberhardt et al. 1997, Eberhardt in press) to generate a "habitat suitability index" for Golden Eagles (Eberhardt et al. 1997). In addition, habitat quality during winter was assessed using a modified model that considered only the period when snow cover occurred (Eberhardt 1996). Home range sizes were determined from direct visual and telemetry observations of eagles by using the Kernel-Estimator (Worton 1989, Naef-Daenzer 1993, Bögel and Eberhardt 1997).

To explain different settlement densities and to identify areas of Golden Eagle concentration within the Alps, the parameter "landscape compartments" which can be derived from ground relief (Brendel et al. 2000) was used, as recommended by Haller (1996).

Model Transformation. The digital database for the European Alps proved to be very heterogeneous with a large amount of variation in quality between different countries and even within regions. For example, the "Arealstatistik" for Switzerland provides information on 73 landcover types derived from 100 × 100 m orthophotos, while the CORINE-classification for Germany, France, Italy, and Austria delineates 44 landcover types derived from 1:100 000 satellite photos. Therefore, for the step-by-step transformation of the detailed models for the Berchtesgaden BR to larger areas and finally to the whole Alps, some important simplifications had to be implemented. For example, landcover types were aggregated into 13 classes considered to be relevant to eagles. Also, we had to increase the scale from 1:25 000 to at least 1:1 000 000 for the whole European Alps because of the lack of comparable, detailed digital elevation models and heterogeneous landcover types across regions. To validate the predictions in these large-scale models concerning habitat quality and distribution, it was necessary to select different test areas within the Alps, which combined high quality observational data as well as digital data (Brendel et al. 2000).

Validation of the Models. A monitoring program, long-term database on Golden Eagles, telemetry data, and detailed knowledge of local experts provided the validation of the models we developed for the study area (Brendel et al. 2000). The predictions for other test areas were validated by comparing the models with local and regional data concerning Golden Eagle distribution and habitat quality. This was done for Kanton Graubünden, Switzerland (Brendel et al. 1998), all of Switzerland, South Tyrol, Italy, Vanoise National Park, France, and the Bavarian Alps, Germany.

Applications in Nature Conservation. The results of the Golden Eagle project at the Berchtesgaden National Park were transformed into management recommendations. One of the most important targets was to promote the acceptance of recommendations in local areas to conserve Golden Eagles. To achieve this, we devel-

oped an extensive environmental education program and close links with user groups like the German Bundeswehr (army helicopters), local paragliders, and climbers. The environmental education program consisted of presentations, public relations efforts, guided tours, and an exhibition as well as "experience trails." These trails lead National Park visitors to places where they have an opportunity to observe Golden Eagles with telescopes at perching and roosting sites and winter feeding areas without disturbing them. The aim was to let people take part in the fascination of eagles and learn about ecological connections within the alpine ecosystem.

Helicopter and paraglider pilots were trained in eagle conservation and were taught how to recognize when eagles are being disturbed and, most importantly, how to avoid disturbing nesting eagles. Blackboards were installed permanently at the launch sites of paragliders informing them about sensitive areas such as breeding cliffs. The boards also showed suggested alternate flight routes that lead them to areas with excellent thermal updrafts, but with a low potential for disturbing eagles.

RESULTS

Modeling and Validation. The literature-based habitat-suitability-models (HSM) for the Golden Eagle that incorporated prey availability, slope/thermal updrafts, and human disturbance in the study area were broadly consistent with radio-telemetry data on the behavior of one territorial female and long-term observation data for 13 eagle pairs in the study area. The essential habitat elements were similar in both summer and winter.

Model predictions concerning the habitat preferences of Golden Eagles also fit the situation in the Bavarian Alps very well. In only a few cases were areas utilized by the eagles not predicted, and some of these represented very special, maybe unique situations in areas in prealpine marshlands where eagles hunt roe deer (*Capreolus capreolus*).

Validation was done by local experts using the same procedures in two test areas: South Tyrol, Italy and the Grisons, Switzerland. Both areas provided similar results showing high correspondence of the habitat-quality predictions. The possibility of identifying "hot-spots" or areas with high habitat quality as well as high settlement density in the eastern Alps was tested for the Grisons, Switzerland and finally for all of Switzerland by calculating settlement-density-models (SDM). SDMs predict settlement density on a scale from low to very high. Comparison of the models with real data showed good correspondence with >95% of 106 actual home range centers (the preferred nest site location of one breeding pair) in the Grisons and 310 breeding pairs within predicted areas of high and

very high settlement density in Switzerland. Small differences between reality and the SDM were analyzed by investigating the impact of skiing facilities on the spatial distribution of eagle pairs and their potential prey species. Some of these differences were related to the presence of skiing facilities and some were not.

Cooperation in Nature Conservation. After establishing close cooperative relationships between conservationists and user groups in 1995, no further human-induced brood failures were documented in the study area. Breeding success increased during the project period from 0.18 young per pair/yr from 1982–87 (Schöpf 1989) to 0.26 young per pair/yr from 1994–2000 (Brendel et al. 2000).

In 1998, one eagle pair started breeding very close to a military helipad. The routes used by the helicopters were changed immediately and the pair bred successfully. Disturbances within 300 m ("primary zones") of nesting Golden Eagles were also avoided during the International Bavarian Paraglider Championships held in Berchtesgaden in 1998 through the cooperation between the organizing committee and the National Park administration to fix routes used during the competitions. The use of permanent blackboards for paragliders in the study area was received very positively. Because of this, a project to use this strategy in other areas of the Bavarian Alps with a similar degree of human pressure has already been proposed.

Environmental Education. Almost 50 000 people have visited the Golden Eagle exhibit and have used the "experience trails" since their establishment in 1998. Hundreds of tourists each year take part at the guided Golden Eagle tours to see this fascinating species in Berchtesgaden. Surveys as well as official visitor statistics show a high degree of approval for these programs.

DISCUSSION

The Golden Eagle population appears to be at capacity in many parts of the European Alps (Brendel 1998). Self-regulation by intraspecific competition is widespread among various populations in Switzerland (Jenny 1992) and possibly in many other regions. Nevertheless, it is a latent Endangered Species in the European Alps (Bauer and Berthold 1996, Haller 1996). Human disturbances close to nests (Bezzel and Prinzinger 1990), disturbances of prey species in their preferred habitats, as well as human-related changes in the spatial ex-

tent of its hunting areas might threaten the alpine population in the future (Brendel et al. 2000). Persecution might also become a factor in the future if protection laws in regions in Austria are changed to allow eagles to be controlled. To secure the population of Golden Eagles in the European Alps in the future, the following requirements must be met: (1) no persecution of Golden Eagles should be allowed throughout the year; (2) habitats essential for Golden Eagles must be identified and conserved throughout its entire alpine range; and (3) disturbances within the "primary zone" around nest sites must be avoided during the sensitive period from March until July.

GIS analysis has already proved to be a useful tool for investigating the habitats of large eagles (Chandler et al. 1992). The identification and evaluation of essential habitats using GIS is an essential step toward understanding the distribution mechanisms of raptors in large areas, like the European Alps. Differences between model-prediction and real habitat preferences will have some importance for local conservation, but will have a negligible effect on conclusions over a larger area. Different settlement densities of the alpine eagle population can also be predicted by implementing the factor "landscape compartments." These distributional "hot spots" might be potential source areas that could compensate for other parts of the range that are in poor or deteriorating condition. Data from the population in Berner Oberland, Switzerland support this hypothesis (Jenny 1992). Assuming that prey abundance is not a limiting factor in the Alps, differences in the sizes of home ranges of breeding pairs (Bezzel and Fünfstück 1994, Zechner 1995, Haller 1996) seem to be simply a product of the predominant geomorphological structure (Brendel et al. 2000).

Habitat suitabilities during winter and summer are related to the amount and availability of thermal updrafts, the availability of prey (carrion, live prey), and the interaction between them in early spring. Models concerning these differences in habitat suitability can provide a better understanding of the importance of thermal "stepping stones" (i.e., slopes that provide good thermal updrafts and their spatial distribution in an area or home range), which might be an important factor in overall habitat quality. This and the availability of food during winter are probably the most important factors for determining whether eagles will be able to breed in the next year (Brendel et

al. 2000). These parameters can be modeled relatively easily using GIS (Bögel and Eberhardt 1997) and might help to predict tendencies in breeding performance of well-known populations.

The impact of human activities like paragliding on the behavior and energy budgets of alpine mammals such as chamois (*Rupicapra rupicapra*) has been extensively discussed (Zeitler 1995). The effects of paragliding on the breeding performance of cliff-nesting raptors like Golden Eagles are rarely considered. It is difficult for pilots and climbers to avoid disturbances by maintaining fixed distances from nests. Habituation of birds to this form of disturbance has not been documented making it impossible to set an objective distance for all situations. A distance of 300 m for paragliders, climbers, and hikers and 500 m for helicopters appears to be reasonable in decreasing breeding failure caused by these activities. The increase in breeding success during the studies in Berchtesgaden was probably not caused exclusively by cooperation strategies, but they may have played an important part in the increase. Changing human behavior by training pilots about conservation issues appears to be a very effective way of reducing disturbances within 500 m of breeding sites. Risk maps for helicopters or permanent blackboards for paragliders complete this successful strategy and provide a higher acceptance among sportsmen and other users than simple prohibitions or extensive regulations (Brendel et al. 2000).

The efficiency of environmental education strategies, like exhibits or "experience trails" is very difficult to measure, but counting the number of visitors who use them can be an appropriate tool to estimate their success.

CONCLUSIONS

Due to its importance as an environmental indicator for areas of open land (Plachter 1990), the Golden Eagle provides many new and interesting tasks for GIS-modeling in connection with future conservation management of alpine landscapes. Calculation of three-dimensional use patterns of home ranges by eagles could be helpful in providing a more detailed explanation of their different distribution patterns in its alpine range. In the future, work using this approach would be facilitated by the construction of a uniform database for the whole of the Alps to be used within a GIS model.

LITERATURE CITED

BAUER, H.-G. AND P. BERTHOLD. 1996. Die Brutvögel Mitteleuropas. Bestand und Gefährdung. Wiesbaden, Aula-Verlag, Germany.

BEZZEL, E. 1976. Vogelarten der Alpen als Weiser naturnaher Lebensgemeinschaften. Jb. Ver. Schutz f. Alpenpfl. u.—tiere 41:9–23.

——— AND R. PRINZINGER. 1990. Ornithologie. 2, völlig neubearb. u. erw.Aufl. Ulmer, Stuttgart, Germany.

——— AND H.-J. FÜNFSTÜCK. 1994. Brutbiologie und Populationsdynamik des Steinadlers (Aquila chrysaetos) im Werdenfelser Land/Oberbayern. Acta Ornithoecol. 3:5–32.

BÖGEL, R. AND R. EBERHARDT. 1997. Modelle zur Bewertung von Thermik und dynamischen Hindernisaufwinden zur Beurteilung der Flugbedingungen für Großvögel. In Angewandte Geographische Informationsverarbeitung IX. Salzb. Geogr. Mat. 26:23–33.

BRENDEL, U. 1998. Vögel der Alpen. Ulmer-Verlag, Stuttgart, Germany.

——— AND W. D'OLEIRE-OLTMANNS. 1996. Managementstrategien zum Schutz des Steinadlers (Aquila chrysaetos) in den Alpen. Naturschutzzentrum Wasserschloss Mitwitz—Materialien I/96:37–43.

———, R. EBERHARDT, AND K. WIESMANN. 1998. The Golden Eagle Aquila chrysaetos as an indicator of key habitats in the European Alps. Ostrich 69:422.

———, ———, K. WIESMANN-EBERHARDT AND W. D'OLEIRE-OLTMANNS. 2000. Der Leitfaden zum Schutz des Steinadlers (Aquila chrysaetos) in den Alpen. Nationalparkrerwaltung Berchtesgaden, Forschungsbericht Nr. 45:112 pp.

CHANDLER, S.K., J.D. FRASER, D.A. BUEHLER, D.J. DEAN, AND J.K.D. SEEGAR. 1992. Using a Geographic Information System to analyse Bald Eagle Haliaeetus leucocephalus habitat on the Chesapeake Bay, Maryland. Pages 337–346 in B.-U. Meyburg and R.D. Chancellor [EDS.], Raptor conservation today. World Working Group on Birds of Prey, Berlin, Germany.

EBERHARDT, R. 1996. Raumnutzung des Steinadlers Aquila chrysaetos (L.) im Biosphärenreservat Berchtes-

gaden. Unveröff. Dipl. Arb. an d. Univ. Saarbrücken, Germany.

———, R. BÖGEL, B. FRÜHWALD, AND A. LOTZ. 1997. Modellbildung zur Raum- und Habitatnutzung terrestrischer Organismen am Beispiel von Steinadler und Gemse. Pages 47–58 in Angewandte Geographische Informations-verarbeitung IX. Salzb. Geogr. Mat. 26: 47–58.

GLUTZ V. BLOTZHEIM, U. 1971. Handbuch der Vögel Mitteleuropas. 4:637–675.

HALLER, H. 1996. Der Steinadler in Graubünden. Langfristige Untersuchungen zur Populationsökologie von Aquila chrysaetos im Zentrum der Alpen. Orn. Beob., Beiheft, Germany.

JENNY, D. 1992. Bruterfolg und Bestandsentwicklung einer alpinen Population des Steinadlers Aquila chrysaetos. Der Ornithologische Beobachter 89:1–43.

NAEF-DAENZER, B. 1993. A new transmitter for small animals and enhanced methods of home range analyses. J. Wildl. Manage. 57:680–689.

PLACHTER, H. 1990. Arten- und Biotopschutz. Arbeitsgemeinschaft Alpenländer ARGE ALP. Bericht über das internat. Symposium 27.03–29.03.1990 in Garmisch-Partenkirchen, Germany.

SCHÖPF, H. 1989. Der Steinadler in den Bayerischen Alpen. Akad. Natursch. Landschaftspfl. (ANL), Laufener Seminarbeitr. 1/89:57–59.

SIEGRIST, D. 1998. Zahlen zu Tourismus und Freizeit. In Alpenreport. Daten, Fakten, Probleme, Lösungsansatze. CIPRA-International (Hrsg.)—Bern, Stuttgart, Germany.

WATSON, J. 1997. The Golden Eagle. T. & A.D. Poyser London, U.K.

WORTON, B.J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70:164–168.

ZECHNER, L. 1995. Siedlungsbiologie und Reproduktion des Steinadlers, Aquila chrysaetos, in den südlichen Niederen Tauern (Steiermark). Unveröff. Dipl.-Arb an der Univ. Graz, Germany.

ZEITLER, A. 1995. Ikarus und die Wildtiere. Grundlagenstudie zum Thema Hängegleiten, Gleitsegeln und Wildtiere. Deutscher Hängegleiterverband e. V, Gmund, Germany.