Constraints, Suggested Solutions and an Outlook towards a New Digital Culture for the Oceans and beyond: Experiences from five predictive GIS Models that contribute to Global Management, Conservation and Study of Marine Wildlife and Habitat

Falk Huettmann

419 Irving I, EWHALE lab, Institute of Arctic Biology, Biology and Wildlife Department, University of Alaska-Fairbanks, Fairbanks AK 99775 USA
E-mail: fffh@uaf.edu

Abstract

Marine wildlife and habitat data are increasingly available to the global public for free and via the internet. This 'data explosion' brings change in ocean management and promotes predictive modelling. Predictive modelling using such data and GIS (Geographic Information Systems) has matured as a robust research method, but still does not get used to its full potential. This study reviews experiences and constraints encountered during 5 predictive GIS models representative for the Atlantic and Pacific. It was found that data availability is less of a problem, but data quality still needs to be improved in time and space. Bigger constraints were found with the management and policy implementations of spatial models. A professional attitude towards the free delivery and use of data, and data availability is required. Often, expertise and skill is still missing on how to set up, build, interpret and implement predictive models towards safeguarding marine wildlife and its habitat. It is suggested that the awareness, education and support for data and modelling needs to be further improved in the public, in agencies and among scientists. Using evaluated models should become a legal requirement when dealing with endangered wildlife and habitat of the global village. A change towards a truly digital and transparent administration and culture, based on science-based management and using models for decision-making, is suggested for the oceans and beyond.

Keywords: Geographic Information Systems (GIS, predictive modelling, databases, marine wildlife and habitat).

Introduction

The rapid increase in data availability for the oceans brings changes. For instance, it affects decision-making and supports spatial and predictive modelling of wildlife species and their habitat. Predictive modelling is a relatively new but already mature research discipline which is still on the rise. Modelling high quality data contributes to conservation, management, research and to a sound decision-making in a complex and fast changing world (Ford, 1999; Sarewitz *et al.*, 2000; Shenk and Franklin, 2001). Often, predictive modelling represents the only method to obtain sound information for marine wildlife and its habitats in larger areas, *e.g.* when only opportunistic samples exist in space and time. This is specifically the case when study areas are large, remote or difficult to access such as coastal areas, pelagic habitats and oceans. However, when trying to apply these predictive modelling methods in the real world and in policy it becomes quickly obvious that major constraints beyond the technical possibilities still exist. From earlier applications elsewhere it was shown that data availability has been the major constraint (Huettmann, 2000a, 2004; Esanu and Uhlir, 2004; Gottschalk *et al.*, 2005), but many examples nowadays can be found where the ocean has received great data projects representing a progressive template for other ecosystems regarding data availability, *e.g.* World Ocean Atlas (WOA, Levitus, 1994), Reynolds fields (http://podaac.jpl.nasa.gov/cgi-bin/dcatalog/fam_summary.pl?sst+), Ocean Biodiversity Information System (OBIS, http://www.iobis.org/; Malakoff, 2003; Zhang and Grassle, 2003). More relevant constraints are still brought by political influences or by traditionally trained field workers, researchers, managers and other groups either not familiar with spatial models and their interpretations or having vested interests (Huettmann, 2005). Many predictive wildlife modelling references exist, either dealing with how to perform statistically accurate modelling (*e.g.* Manly *et al.*, 2002), how to link them with biological mechanisms (*e.g.* Nakazawa *et al.*, 2004), or apply them in terrestrial applications (*e.g.* Scott *et al.*, 2002), but less so with ocean-wide, large-scale marine wildlife and biodiversity (*e.g.* Valavanis, 2002; but see Rozwadowski, 2002). Wildlife and habitat modelling techniques are complex and require multidisciplinary approaches; they often have to consider many aspects of humans and human behaviour as well in order to be successful (Huettmann, 2004).

In order to complement and further improve the existing and traditional information about marine wildlife with advanced modelling, here I present and analyze some experiences from representative modelling and model building projects in the Atlantic and Pacific dealing with a variety of marine conservation topics and marine wildlife species. Specifically, I outline issues which still need to be overcome towards more progressive and science-based management modelling in order to safeguard the natural wildlife and habitat resources of the global oceans (*e.g.* in an adaptive management framework; Walters, 1986). The presented model projects are using free data and are based on progressive and multidisciplinary studies. All of which have a field work component and where modelling contributes new insights and guidance for science and for the management process. Most of the studies discussed here try to model species habitat relationships and to predict spatial distributions, populations and future habitat states. However, for completeness, issues such as population modelling and other topics related to marine modelling also get addressed.

Methods

In the following, I describe model data sets and individual methodologies from five selected modelling projects which can get considered as a representative set of predictive ocean species models. This allows drawing general conclusions for improving modelling exercises world-wide. All of the data mentioned here refer to GIS-layers in Arc View 3.3.

Case study 1: Pelagic Seabird Species and Colony Distribution in the Northwest Atlantic.

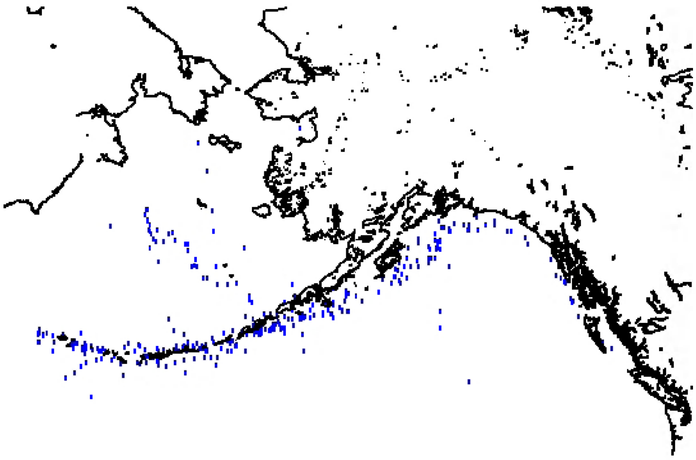
Seabird distribution of four abundant species (Northern Fulmar *Fulmarus glacialis*, Atlantic Puffin *Fratercula arctica*, Common Murre *Uria aalge* and Northern Gannet *Morus bassanus*), derived from pelagic surveys carried out during more than 25 years (1966-1992) in the Northwest Atlantic (Gulf of Maine – Canadian High Arctic) were related to marine features. Marine habitat data were available for free *e.g.* from the internet for Comprehensive Ocean-Atmosphere Data Set (COADS http://www.cdc.noaa.gov/coads/), World Ocean Atlas (Levitus, 1994), ETOPO5 and others. Seabird survey data were provided in a digital format by T. Lock and R.G.B. Brown, Canadian Wildlife Service (for more details on data and methods see Huettmann and Lock, 1996; Huettmann, 2000a). These seabird-habitat relationships were quantified using primarily a multiple regression approach predicted to locations with a known set-up of environmental features, and which get finally evaluated for its performance. More details can be found in Huettmann and Diamond (2001).

*Case study 2: Marbled Murrelets (*Brachyramphus marmoratus*) in coastal Old-Growth Forest habitat of British Columbia, Canada.*

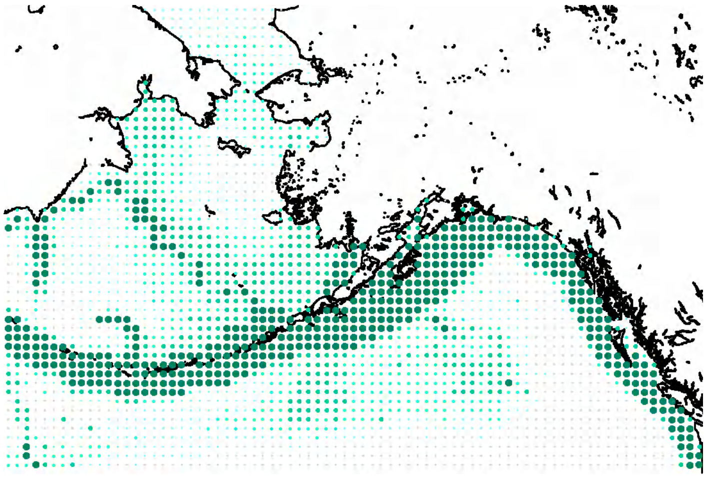
Marine abundance and potential nest occurrence information of the Marbled Murrelet, a seabird species of international conservation concern, were related to the marine and terrestrial features. Marbled Murrelet data came from Burger (1995) and other published sources; environmental data were taken from NOAA (National Oceanic and Atmospheric Administration Coastwatch, 2000) and others. The habitat preference was quantified using linear and non-linear models. These statistical relationships were then predicted to coastline locations with a known set-up of environmental features. Secondly, population estimates were also derived from these spatial models. More details about this study can be found in Yen *et al.* (2004).

Case study 3: Predicting the pelagic distribution of Short-tailed Albatross (Phoebastria albatrus) in the Northern Pacific using 'Presence Only' data.

Compiled opportunistic and historical albatross sightings ('presence only' data) already provided for free on the internet (http://www.iphc.washington.edu/staff/tracee/shorttail.htm; see Figure 1a) were used to describe the ecological niche of an endangered seabird, the Short-tailed Albatross. The primary focus of this study was to describe from Alaskan sightings as training data the distributional range of this species in the adjacent Russian and Canadian waters and for which only very few or none sightings and incomplete information exist (Figure 1b; FH unpublished).



a) Dots indicate a sighting; usually during July and August from 1940-2000.



b) Size and intensity of point indicates magnitude of the index of occurrence across months and years.

Fig. 1. a) Raw sightings ('presence only'), and (b) predictions of Short-tailed Albatross distribution throughout the year in the Northern Pacific using MARS algorithm.

Case study 4: Modelling the distribution of nesting waterbirds in the subarctic Great Slave Lake using opportunistic sightings.

The Great Slave Lake presents a major and large waterbody in the North American subarctic. Due to its general inaccessibility, it is widely unsurveyed and only limited information on nesting waterbirds exist, published in the grey literature. Opportunistic surveys (Sirois *et al.*, 1995) were used trying to derive nesting/colony distribution and abundance estimates of nesting pairs. Environmental data were used from topographical maps, climate models and remote sensing imagery. The goal of this study was to improve distribution information, to assess scale effects and to obtain first population indices for this otherwise widely unsurveyed area. Further details regarding this study are found in Fenske (2003).

Case study 5: Modelling the future coastal ecosystem of Marbled Murrelets to assess spatially explicit impacts on distribution and abundance in British Columbia.

This study is currently 'in progress' (FH *et al.* unpublished) and deals with a major contribution brought by predictive modelling: Forecasting the state of habitats for an endangered species. It is based on the initial model study presented by Yen *et al.* (2004), and tries to replace the current habitat layers - marine and terrestrial - with future scenarios in order to forecast eventually a distribution and population estimate for Marbled Murrelets for entire British Columbia and beyond. The ‘future’ is defined as 10, 50 and 100 years from present (see also Huettmann *et al.*, 2005 for methods). This project will allow obtaining a spatial Population Viability Analysis (sPVA) for a seabird species that became of international conservation due to the ongoing habitat degradation, *e.g.* logging of the old-growth forest nesting habitats, and disturbances in the marine environment.

Results

The following section summarizes the key components and experiences from each of the five models.

Case Study 1

Major Contribution of the Model: Results from this model present for the first time a consistent seabird distribution map which covers the entire North West Atlantic (compare with Brown *et al.* 1975, Brown 1986 for shipboard observations).
Modelling Method: Generalized Linear Models (GLM) and Classification and Regression Tress (Cart-SPLUS) were used.
Constraints encountered during the Model Building Process: Data quality of seabird and environmental data was coarse. Detailed knowledge about the biologically available habitat for seabirds was missing. Earlier views from experts of ‘how seabirds would respond to the marine environment’ biased the model building and model testing initially, and had to be overcome and revised. Lack of an interdisciplinary research

environment and software technology, including technical and administrative infrastructure problems, presented delays to complete the project efficiently.
<u>Constraints due to Data Accessibility:</u> None, since internet was used (for environmental data); seabird data were efficiently provided by governmental agency. Some seabird data had to be added, and restored from back-ups and hard copies; quality checks were required.
<u>Constraints encountered during Model Implementation:</u> The governmental management process did not consider results from modelling for more than five years. Local expertise is missing to comprehend and implement findings from these models.

Case study 2

<u>Major Contribution of the Model:</u> The resulting distribution map allowed for the first time for a consistent distribution information of Marbled Murrelets for the entire coastline of British Columbia. These estimates were derived from consistent methods and data, and also allowed for the first time for a modelled population estimate, obtained from compiled, best scientific available information for this species of major conservation concern.
<u>Modelling Method:</u> GLM, Cart-SPLUS, CART-Salford, Multiple Regression Splines (MARS-Salford) and Neural Networks (SPLUS) were applied.
<u>Constraints encountered during the Model Building Process:</u> The data quality of Marbled Murrelet abundance and locations, as well as the environmental data was coarse; Metadata of the Marbled Murrelet data did not exist. Knowledge about available habitat for seabirds was missing. Initial views by experts of 'how Marbled Murrelets would respond to the marine and terrestrial environment' and at what scale biased model building severely and had to be overcome (Huettmann *et al.*, in review). Political views about Marbled Murrelet research complicated and delayed the project and data availabilities strongly.
<u>Constraints due to Data Accessibility:</u> A centralized database of all known Marbled Murrelet nests and abundances was not available (but see http://www.sfu.ca/biology/ wildberg/ species/ mamu.html); many data sets had to be located, assessed, digitized and merged from numerous individual contractors and data holders who work small scale but lack seeing the large picture. Alternative data sets had to be obtained from NGO and internet sources.
<u>Constraints encountered during the Model Implementation:</u> Management process did not consider results from modelling, yet. Counter models were initiated and used to circumnavigate findings from this model. The use of AIC (Burnham & Anderson 2002) for model selection, instead of traditional significances and p-values, created a major problem in the acceptance of results from this model. Local expertise is missing to comprehend and implement model findings.

Case study 3

<u>Modelling Contribution:</u> For the first time, a pelagic distribution map of Short-tailed Albatross in the Northern Pacific was predicted.
<u>Modelling Method:</u> MARS-Salford was applied to 'presence only' data.

Constraints encountered during the Model Building Process: Local experts and governmental agencies claimed a monopoly for dealing with this species and discouraged large-scale model-building to this very day. Due to competitive funding and internationally pending legal conservation tensions the modeller was threatened and marginalized for going ahead building predictive models on Short-tailed Albatross for international peer-reviewed research publications. Lack of funding to build model, compile and work up data had to be overcome.
Constraints due to Data Accessibility: None; all data are freely and fully available on the internet/WWW.
Constraints encountered during the Model Implementation: So far, the model was ignored by the Short-tailed Albatross research community, as well as by governmental and other agencies with a mandate to manage seabirds.

Case study 4

Modelling Contribution: For the first time, a consistent distribution and abundance information of waterbirds in the subarctic Great Slave Lake was produced.
Modelling Method: GLM, CART-Salford, MARS-Salford and Neural Network SPlus using 'Presence Only' data.
Constraints encountered during the Model Building Process: Governmental agency did not fully collaborate; otherwise, no relevant constraints were encountered.
Constraints due to Data Accessibility: Data were not available or known for this project and had to be compiled, created and digitized.
Constraints encountered during the Model Implementation: The model was not considered by governmental agencies for conservation and management actions, yet.

Case study 5

Modelling Contribution: Future Marbled Murrelet habitat, distribution and abundance.
Constraints encountered during the Model Building Process: Some landowners did not provide growth and yield information, nor were they to motivate buying into an overall and mutually accepted modelling approach. Lack of data accuracy was used to block and delay the modelling process. Missing funding and seeing the importance of this work by governmental agencies had to be overcome.
Constraints due to Data Accessibility: Due to the lack of 'buy-in', landcover data as the crucial source for model building were constantly criticized.
Constraints encountered during Model Implementation: Competing models were developed from opposing lobbies on a smaller scale, presenting their own models and views into the political discussion.

Discussion

The review of modelling studies for marine wildlife and habitat shows that some consistent constraints occur within predictive modelling projects, harming crucial progress on this subject. These constraints have not been shown or explained and outlined in earlier modelling publications. Considering that modelling and its importance will increase I believe it is very important to outline and review modelling constraints for a wider audience in order to address them. Earlier topics important enough to halt entire modelling projects such as GIS, software analysis code and data availability were not considered as a major constraint anymore (see also Huettmann and Linke, 2003, Esanu and Uhlir, 2004, Gottschalk *et al.*, 2005). Instead, subjects related to the lack of technical and statistical expertise by implementing agencies, biased expert views or vested interests were mentioned most often as constraining modelling projects and their acceptance (see also Rozwadowski, 2002 for policy applications and political influences on science-based models). Topics like data quality (*e.g.* content and spatial) and data transfer/copyrights were mentioned less often, but still could block modelling work dramatically for charismatic and important wildlife species and biodiversity in general (see Graham *et al.*, 2004 for terrestrial biodiversity applications); it impairs the general acceptance of models. Spatial predictive modelling is often the only means to provide estimates of marine wildlife distribution and abundances, *e.g.* in pelagic and coastal wilderness areas that are difficult to access (Huettmann, 2000b). The advantage of modelling is that it is derived from a consistent and transparent methodology, that it can be repeated (=evaluated by other parties), and its performance assessed (Fielding and Bell, 1998; Ydenberg, 1998; Pearce and Ferrier, 2000) towards a better scientific understanding and higher trustworthiness in the management process and for public policy. I feel that these steps provide a major argument in favour of building and applying models. Once a model has been build, and a modelling culture is set up, poor models can always, and relatively easy, be improved, *e.g.* in the framework of scientific hypothesis testing. Considering such a situation and the major contributions that can be obtained through the use of predictive modelling, it is surprising to learn that the use of spatial modelling in conservation management is still not well advanced and not used more effectively (Bookhout, 1994; Primack, 1998, but see Walters, 1986; Brown *et al.*, 2000 and MARXAN http://www.ecology.uq. edu.au/index.html?page=20882 for Marine Protected Areas MPAs), nor is it built in as a requirement into the legislation of endangered species and habitat (see for instance Czech and Krausman, 2001) or in the Ocean Act and organizations administrating oceans of the world (Rozwadowski, 2002 for ICES).

Despite the experiences from the models presented here, one might find of interest as well the numerous modelling projects which eventually could not be carried out due to various constraints. At least six of such modelling projects come to mind to the author; they usually failed due to data access issues from individuals with an interest in the data themselves. Other constraints were caused by the general lack of support, *e.g.* financial and man-power, for collecting and digitizing data, for building models and for evaluating them statistically. Although financial constraints exist, other reasons for failing predictive modelling projects are brought by poor data quality and lack of awareness on the benefits of modelling, *e.g.* beyond borders. Besides failed projects, one should also consider the tremendous delay of model projects caused when data and model issues occur. One problem is for instance that even within governmental agencies, data are sometimes not well known, documented with Metadata, heavily delayed, not shared or plainly not available. Vested interests brought by promotion/salary, money/fieldwork funds and publication rights further proof counterproductive to modelling and its exciting advances for the global village.

All models reviewed, as well as many others in the literature (Manly *et al.*, 2002; Scott *et al.*, 2002), primarily deal with correlations but less with the true biological mechanisms to explain wildlife distribution and abundance. This is less of a technical modelling issue but more a data issue since biologically meaningful marine biodiversity and prey information, *e.g.* benthos, plankton and non-commercial fish databases collected with a consistent protocol are often still missing. The modellers should be more explicit in requesting these crucial data sets in order to further improve biological models and predictions.

The author found that advances of scientific exploration and innovation, such as represented by modelling, can be constrained by administrative hierarchy, and most importantly, by old-fashioned peer-review policies of grants and publications. Old-fashioned hard copy project reports do not prove helpful, but the underlying digital data are needed as well. Also, funding agencies are able to reduce global progress severely for advanced problem solutions, when monopolizing their influence on research; hiring and distribution of public funds (see Paehlke, 2004 for an entrenched 'Cult of Incompetence'). However, they also have the opportunity to promote any of these fields further towards a modern society using appropriate tools. I suggest that modelling definitely requires an appropriate funding structure for assuring progress. Setting up such a culture and infrastructure requires a sophisticated and contributing leadership with a global vision.

Models allow bringing people and lobbies together and locating data gaps to be overcome and improved with subsequent fieldwork and modelling (Scott *et al.*, 2002). Models offer the great advantage to be constantly improved and fine-tuned. Also, predictive modelling, as presented here, offer a major contribution in order to obtain a Population Viability Analysis that takes spatial issues serious. I believe that this subject should receive more attention because it can address a key topic in management, populations and habitats, in pro-active terms and before unwanted situations occur, *e.g.* Huettmann *et al.* (2005).

Depending on the wildlife species, on the type of habitat and the human dimension, some problems are more important than others for advanced modelling. However, due to the complex situations of most models currently one cannot present an always valid cookbook approach to successful wildlife and habitat modelling projects.

From the modelling experience, it was found that successful modelling requires manifold skills rarely taught at universities and during marine wildlife education, yet. They go beyond pure marine wildlife, fisheries, statistical and computer skills. Many pitfalls and problems can occur during such applications, and few published experiences, rules or standards exist how to improve marine wildlife and conservation modelling projects, how to avoid errors and how to implement models eventually in the political and legal decision-making process addressing conservation and sustainability. More guidance is needed. It was found that often an old-fashioned institutional culture has to be overcome first, and then replaced with a new digital one that handles spatial and interdisciplinary models as well as all of the related issues. This can turn into a non-trivial task. Many political, strategic and diplomatic approaches are still required to deal with subjective, and often unprofessional, attitudes towards spatial modelling. Valuable lessons can be learned here from the Remote Sensing discipline for instance, which similarly went through a learning phase and has now reached maturation and general acceptance (Franklin, 2001; Gottschalk *et al.*, 2005).

One should emphasize that highly accurate (spatial) predictions should be the goal for modelling projects because a generalized inference, and testable hypothesis, can be brought forward for a quantitative assessment, and if necessary, model improvement. This new culture counters the old-fashioned believe that only field observations are valid and convincing for a generalized inference in biological disciplines. I believe that modelling should remain open-minded and consider alternatives. Findings can still depend on the nature of the modelling algorithm, *e.g.* when it comes to the selection of predictors and actual spatial predictions. Therefore, a competitive multi-model approach should be encouraged (Burnham and Anderson, 2002) and I suggest assessing and challenging the traditional approaches such as simple hypothesis testing with p-value thresholds, and hand-drawn distribution maps from experts and GLM models as the ultimate paradigms. Instead, and in times of great data availability and high technological tools, one should promote that model project repeats and duelling models are wanted as a form of true hypothesis tests towards science-based adaptive management (Walters, 1986), improved models and decision-making of public resources using the best science principle (Sarewitz *et al.*, 2000). Therefore, sound assessments of model accuracies are crucial, and it is suggested to fully support any of these approaches, including the collection and compilation of alternative assessment data and evidences.

Conclusions and Outlook

Due to the existence of free data sets, predictive models are maturing and prove to be of major value to management. Data availability is increasingly less of a problem, but data quality and resolution still needs to be steadily improved on a global scale. Biologically meaningful marine biodiversity and prey information such as high-quality benthos, plankton and fish databases collected with a consistent protocol are still needed. The data overkill of the future needs to be tamed with appropriate software tools (Huettmann, 2005).

Competing models are part of a scientific investigation using hypothesis; they are required and important to improve spatial models and eventually increase model trust. Once evaluated, many models still lack their implementation into policy and management, and it is suggested to quickly improve this situation on a global scale towards a new digital data and model culture of the oceans and beyond for the global village. The awareness, education and support for modelling needs to be further improved in the public, agencies and among scientists and lawmakers. Modelling should become a legal requirement when dealing with endangered wildlife and habitat.

Acknowledgements

I gratefully acknowledge the approaches brought forward by S. Levitus at NOAA who presented a great vision for the oceans and beyond, often still not reached on this scale in terrestrial systems and globally. Further, I would like to thank all data providers and all individuals and agencies who make their data available to research, to students and to the public, free of charge and online. I am further grateful to B. MacDonald and A.W. Diamond for introducing me into modelling, and J and S. Linke for initial support and discussions. Salford Systems kindly provided some of the modelling software. V. Reifenstein helped with the figures. The conversation with L. Strecker, EWHALE lab members, and support from B. Bluhm was highly appreciated. An NCEAS workshop on 'Alternative Modelling Techniques' allowed for a tremendous support and opportunity complementing my knowledge on modelling science. This is EWHALE publication number 23.

References

Bookhout T.A. 1994. Research and Management Techniques for Wildlife and Habitats. Wildlife Society, Bethesda, MD

Brown R.G.B. 1986. Revised Atlas of Eastern Canadian Seabirds. Canadian Wildlife Service, Ottawa

Brown R.G.B., D.N. Nettleship, P. Germain and C.E. Tull. 1975. Atlas of Eastern Canadian Seabirds. Canadian Wildlife Service, Ottawa

Brown D., H. Hines, S. Ferrier and K. McKay. 2000. Establishment of a biological information base for regional conservation planning in north-east New South Wales. NSW National Parks and Wildlife Service. Occ. Paper 26

Burger A.E. 1995. Marine distribution, abundance, and habitats of Marbled Murrelets in British Columbia. In: Ralph CJ, Hunt GL, Raphael MG, Piatt JF (eds.) Ecology and Conservation of the Marbled Murrelet, Gen. Tech. Rep. PSW-GTR-152. Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany:295-312.

Burnham K. and D.R. Anderson. 2002. Model selection and multi-model inference: a practical information-theory approach. Springer, New York.

Czech B. and P. Krausman. 2001. The Endangered Species Act: History, Conservation and Public Policy. Johns Hopkins University Press.

Esanu J.M. and P.F. Uhlir. 2004. Open Access and the Public Domain in Digital Data and Information for Science: Proceedings of an International Symposium. U.S. National Committee for CODATA, National Research Council.

Fenske J. 2003. Modelling Waterbird Colonies of the Great Slave Lake, Northwest Territories, Canada: A predictive GIS Model of Species Occurrenec of Arctic and Black Terns, and American White Pelicans. Unpublished M.Sc. Thesis, University of Potsdam, Germany.

Fielding A.H. and J.F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Env. Cons.24:38-49.

Ford A. 1999. Modelling the Environment: An Introduction to System Dynamics Modelling of Environmental Systems. Island Press.

Franklin S.E. 2001. Remote Sensing for Sustainable Forest Management. Lewis Publishers, Boca Raton.

Gottschalk T., F. Huettmann and M. Ehlers. 2005. Thirty years of analysing and modelling avian habitat relationships using satellite imagery data: a review. Int. J. for Rem. Sens. 26:2631-2656.

Graham C.H., S. Ferrier, F. Huettmann, C. Moritz and A.T. Peterson. 2004. New developments in museum-based informatics and applications in biodiversity analysis. Trends in Ecol. and Evol. 19:497-503.

Huettmann F. 2005. Databases and science-based management in the context of wildlife and habitat: towards a certified ISO standard for objective decision-making for the global community by using the internet. J. of Wildl. Manage. 69:466-472.

Huettmann F. 2004. Towards a Marine Environmental Information System (MEnvIS) for the Northwest Atlantic: Experiences and suggestions from a multi-disciplinary GIS conservation research project using public large scale monitoring and research data bases from the internet. 4th WSEAS (World Scientific and Engineering Academy and Society) Proceedings, Tenerife/Spain, December 2003.

Huettmann F. 2000a. Making use of public large-scale environmental databases from the WWW and a GIS for georeferenced prediction modelling: A research application using Generalized Linear Models, Classification and Regression Trees and Neural Networks. In: Tochtermann K and Riekert W.-F. (Eds.) "Hypermedia im Umweltschutz" Proceedings of Deutsche Gesellschaft für Informatik (GI) and Forschungsinstitut für anwendungsorientierte Wissensverarbeitung (FAW) Ulm. Umwelt-Informatik aktuell; Bd.24, Metropolis Verlag/Marburg. pp. 308-312.

Huettmann F. 2000b. Seabirds in the Marine Wilderness of the western North Atlantic. Sixth World Wilderness Congress Proceedings, Bangalore/India, Vol. II, Proc. RMRS-P-000. Ogden, UT, US Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Huettmann F. and A.W. Diamond. 2001 Seabird colony locations and environmental determination of seabird distribution: A spatially explicit seabird breeding model in the Northwest Atlantic. Ecol. Mod. 141:261-298.

Huettmann F. and J. Linke. 2003. An automated method to derive habitat preferences of wildlife in GIS and telemetry studies: A flexible software tool and examples of its application. European J. of Wildl. Res. 49:219-232.

Huettmann F. and A.R. Lock. 1997. A new software system for the PIROP database; data flow and an approach for the seabird-depth analysis. ICES J. for Mar. Science, 54:518-523.

Huettmann F., S.E. Franklin and G.B. Stenhouse. 2005. Developing Future Landscape Scenarios for Grizzly Bear Habitat. Can. Forestry Chronicle 81:1-13

Huettmann F., D. Lank, E. Cam, R. Bradley, L. Tranquilla-McFarlane, L. Lougheed, C. Lougheed, P. Yen, Y Zharikov, N. Parker and F. Cooke (in review). Nest habitat selection of Marbled Murrelets (*Brachyramphus marmoratus*) in a fragmented Old Forest Landscape. Journal of Wildlife Management.

Levitus S. 1994. World Ocean Atlas 1994, 4 volumes, Washington, D.C., National Oceanic and Atmospheric Administration, National Oceanographical Data Center.

Malakoff D. 2003. Scientists counting on census to reveal marine biodiversity. Science. 302:773.

Manly F.J., L.L. McDonald, D.L. Thomas, L.T. McDonald, W.P. Erickson. 2002. Resource Selection by Animals. Kluwer Academic Publishers.

Nakazawa Y, A.T. Peterson, E. Martinez-Meyer and A.G. Navarro-Siguenza. 2004. Season niches of Nearctic-Neotropical migratory birds: implications for the evolution of migration. Auk 121:610-618.

National Oceanic and Atmospheric Administration NOAA. 2000. Coastwatch: West Coast Regional Node, Pacific Grove, CA. http://cwatchwc.ucsd.edu/cwatch.html. Accessed May 2002

Paehlke R. 2004. Democracy's Dilemma: Environment, Social Equity, and the Global Economy. MIT Press, Cambridge Massachusetts.

Pearce J.L. and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecol. Mod. 133:225-245.

Primack R.B. 1998. Essentials of Conservation Biology. 2. Edition. Sinauer Associates Publishers.

Rozwadowski H.M. 2002. The sea knows no boundaries: a century of marine science under ICES. University of Washington Press, University of Columbia Press.

Sarewitz D.R., A. Pielke and R. Byerly. 2000. Prediction: Science, Decision Making and the Future of Nature. Island Press.

Scott M.J., P.J. Heglund, M.L. Morrison, J.B. Haufler, M.G. Raphael, W.A. Wall and S.A. Samson. 2002. Predicting Species Occurrences: Issues of Accuracy and Scale. Island Press, Washington.

Shenk T.M. and A.B. Franklin. 2001. Modelling in Natural Management: Development, Interpretation, and Application. Island Press. Washington.

Sirois J., M.A. Kay and M.A. Fournier. 1995. The colonial waterbirds of Great Slave Lake, Northwest Territories: an annotated atlas. Occasioanl Papers, Canadian Wildlife Service No. 89. Ottawa.

Valavanis V. 2002. GIS Applications in Oceanography and Fisheries. Taylor and Francis.

Walters C. 1986. Adaptive Management of Renewable Resources. Blackburn Press, Caldwell New Jersey.

Ydenberg R.C. 1998. Evaluating models of departure strategies in alcids. Auk 115:800-801.

Yen P., F. Huettmann and F. Cooke. 2004. Modelling abundance and distribution of Marbled Murrelets (*Brachyramphus marmoratus*) using GIS, marine data and advanced multivariate statistics. Ecol. Mod. 171:395-413.

Zhang Y. and J.F. Grassle. 2003. A portal for the Ocean Biogeographic Information System. Oceanologica Acta. 25 (5):193-197.