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Review

Spatial Epidemiology and GIS in Marine Mammal Conservation Medicine and Disease Research

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Abstract: The use of spatial epidemiology and geographical information systems (GIS) facilitates the incorporation of spatial relationships into epidemiological investigations of marine mammal diseases and conservation medicine. Spatial epidemiology is the study of the spatial variation in disease risk or incidence and explicitly addresses spatial structures and functions that factor into disease. The GIS consists of input, management, analysis, and presentation of spatial disease data and can act as an integrative tool so that a range of varied data sources can be combined to describe different environmental aspects of wild animals and their diseases. The use of modern spatial analyses and GIS is becoming well developed in the field of marine mammal ecology and biology, but has just recently started to gain more use in disease research. The use of GIS methodology and spatial analysis in nondisease marine mammal studies is briefly discussed, while examples of the specific uses of these tools in mapping, surveillance and monitoring, disease cluster detection, identification of environmental predictors of disease in wildlife populations, risk assessment, and modeling of diseases, is presented. Marine mammal disease investigations present challenges, such as less consistent access to animals for sampling, fewer baseline data on diseases in wild populations, and less robust epidemiologic study designs, but several recommendations for future research are suggested. Since location is an integral part of investigating disease, spatial epidemiology and GIS should be incorporated as a data management and analysis tool in the study of marine mammal diseases and conservation medicine.

Keywords: spatial epidemiology, GIS, marine mammals, conservation, medicine

Introduction

There is a growing awareness among the veterinary and human health professions of the importance of the link between human and animal health and environmental conditions, particularly in the context of species conservation (Deem et al., 2001; Aguirre et al., 2002b). Pathogens may use many different methods to disperse from an infected to an uninfected host. As a consequence, factors that affect the spatial patterns of pathogens, hosts and vectors, and their probability of close contact, are fundamentally crucial to disease dynamics. Several ecological processes can result in strong spatial patterns of risk or incidence. For example, pathogen dispersal might be highly localized, reservoirs of pathogens may be restricted spatially, or there might be clumping of susceptible hosts. Environmental changes due to anthropogenic activity such as climate change and pollution have been associated with disease states in human and animal populations. As an example, warming trends and rainfall patterns can affect the epidemiology of various infectious

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diseases (Harvell et al., 1999). Pathogens, along with habitat loss, overexploitation, human disturbance, and pollution, are becoming more important factors in the conservation of species (Lafferty and Gerber, 2002; Smith et al., 2006). Some marine mammal mass mortality events (Heide-Jørgensen et al., 1992) and new epidemics of infectious diseases (Herbst, 1994; Berger et al., 1998) have been hypothesized to be directly or indirectly caused by environmental pollution.

The study of all these factors as they apply to conservation of marine mammals requires the integration of many disciplines, one of which is epidemiology, particularly spatial epidemiology and geographic information system (GIS) technology. Since a goal of conservation and disease research is to pursue ecological health, and thus the health of ecosystems and their inhabitants, spatial epidemiology and GIS are two of the many tools available that can assist in the research and management of human and wildlife diseases. Marine mammals may serve as indicator species of disturbances reflecting changes in coastal marine environment health and allow prediction of environmental health trends in the marine ecosystem (Aguirre et al., 2002a). Over roughly the last decade, computerization of spatial data, through the use of GISs, has emerged as a tool for marine mammal conservation and disease research. No single review has covered both spatial epidemiology and GISs. The purpose of this article is to briefly review the basic concepts of spatial epidemiology and GIS, introduce the intersection of these tools with conservation and disease research, highlight recent examples of their application to marine mammal conservation efforts and disease studies, and identify major gaps in knowledge, techniques, and resources. Although the potential relevance of spatial analysis and GIS in the marine mammal field has been recognized for many years (Reynolds and Haddad, 1990; Hoover-Miller, 1992), most applications have focused on delineating habitat, foraging, and migration of marine mammals and will be presented briefly. Given the recognition that alterations in habitat, climate, and oceanographic features may also influence disease ecology and transmission, the modern application of spatial epidemiology and GIS to marine mammal disease research has emerged in the last few years and will be the focus of this review.

Spatial Epidemiology

Spatial epidemiology is the study of the spatial variation in disease risk or incidence. It explicitly addresses spatial structures and functions that factor into disease, taking into account the geographical variation in disease with respect to demographic, environmental, behavioral, socioeconomic, genetic, and infectious risk factors (Elliott and Wartenburg, 2004). There is a growing interest in spatial epidemiology due to increased public interest in environmental effects on animal and human health, particularly oceans and human health (Harvell et al., 1999), the development of statistical and epidemiological methods for investigating spatial aspects of disease and disease clusters, the recent collection and availability of health data at different geographical scales (local versus statewide), greater access to once proprietary or "mothballed" spatial data, and probably of greater importance is increased desktop computing power and methods such as GIS.

Several general disease study types utilize spatial elements. The first, disease mapping, provides a visual summary of disease occurrence over space and time, and can aid in better visualization of ongoing disease occurrence and predicting future epizootics (Ostfeld et al., 2005); second, spatial regression studies, which are similar in basic concept to linear and logistic regression. If one is specifically interested in an association between risk factors and exposures at an area level, standard statistical techniques can be used, or alternatively "geostatistical" methods such as Bayesian models may be utilized (Lawson et al., 1999). Third, disease cluster detection and analysis employs the use of spatial elements (Carpenter, 2001).

Geographic Information System

A GIS is a powerful tool for processing, interpreting, and analyzing spatial data. It is a computer-based system for the capture, storage, manipulation, analysis, and display of spatially referenced data (Durr and Gatrell, 2004). GIS is an excellent resource for marine research because it allows the spatial exploration of marine phenomena.

Monitoring physiological effects of environmental and human disturbance may be enhanced by coupling with GIS technology. Complex interrelationships between an animal's environment and emerging diseases are ideally suited for GIS technology, as disturbances, animal densities, habitat differences and usage, and extent of human encroachment may be georeferenced as disparate layers on a GIS. Advances in the use and development of remote sensing techniques and data, combined with GIS, have provided new tools for the study of marine mammal diseases and conservation in relation to emerging diseases, changing ecosystems, and climate. Wildlife veterinarians and biologists are beginning to map important marine diseases using GIS technology to identify known distribution of diseases, including morbillivirus and harmful algal blooms (Scholin et al., 2000). GISs can be used to generate maps and data, as well as perform some spatial analytical techniques useful in epidemiology and conservation (Moore and Carpenter, 1999; Pfeiffer, 2000).

Intersection of Spatial Epidemiology, GIS, and Marine Mammal Disease Research

The role of disease in species conservation has been understood for several years, but only recently have the topics of health and disease become recognized in conservation biology as limiting factors in wildlife conservation (Meffe, 1999; Daszak et al., 2000; Osofsky et al., 2000). Infectious diseases, which include parasites, are a concern for conservation medicine for several reasons such as in determining threats to species, estimating population viability in response to pathogen exposure, recovery programs, and captive breeding (Scott, 1988; Lafferty and Gerber, 2002). Emerging infectious diseases may survive in wildlife reservoirs threatening domestic animal and human health, and may threaten the conservation of global biodiversity (Daszak et al., 2000). Disease transmission can be facilitated by several key threats to biodiversity such as habitat alteration and destruction, introduced plant and animal species, pollution, and climate change (Daszak et al., 2000; Lafferty and Gerber, 2002; de Castro and Bolker, 2005). Spatial epidemiology and GIS may be used as an aid in considering infectious diseases in analyses of extinction risk.

Applications of GIS and Spatial Analysis to Marine Mammal Ecology (Studies Not Specific to Diseases) (Table 1)

Remote Sensing of Environmental Factors

Environmental factors such as oceanographic and climatic features may be integrated into static or interactive maps through the use of a GIS and spatial analyses. Factors such as sea surface temperature, winds, chlorophyll concentrations, ocean depth, and El Niño events may be used to develop explanatory or predictive models of habitat use, migration and foraging patterns, and potential conflicts with vessel traffic or fisheries (Guisan et al., 2002). The models can be used by scientists and resource managers in developing recovery and conservation plans of endangered (and nonendangered) marine mammals.

Stock Assessments

GIS and spatial analyses have been used to plan, interpret, and analyze marine mammal surveys in order to provide data for stock assessments. These assessments provide data on the abundance, life history, migration, diet, behavior, and distribution of marine mammal species (Forney et al., 2000).

Habitat Delineation and Conservation

Coastal, marine, and riverine habitats serve a variety of functions that support many forms of life, including marine mammals. Many complex, interrelated factors that affect habitat health must be understood to effectively manage environmental resources. Environmental factors such as water chemistry, species distribution, anthropogenic variables such as pollution, population growth, and construction, must be evaluated. GIS analyses have been used to visualize spatial relationships between marine mammals and their habitats, helping to define and model population structures, foraging preferences, and critical habitats for conservation efforts. Several academic and government agencies have organized spatially referenced databases with public or member access to facilitate this goal (Read et al., 2008).

Applying Spatial Epidemiology and GIS to Marine Mammal Disease Research

Veterinary epidemiologists face several challenges in trying to detect and sample marine mammal species in order to study their diseases. Boundaries defining stocks or populations are often poorly delineated, complicating efforts to define the location and number of animals in a population of interest. Other challenges include the logistical difficulty frequently encountered in capturing and testing wild animals, and the paucity of validated tests in these species. Nevertheless, advances in tracking technology, spatial database management tools, and wide availability of spatial

Table 1. Uses of GIS and Spatial Analyses in Marine Mammal Conservation (Nondisease Research)

Application	Species	Location	Reference
Migration and movement			
	Bowhead whale *Balaena mysticetus*	Alaska, USA	Davies (1997)
	Leopard seal *Hydrurga leptonyx*	Eastern Antarctica	Rogers et al. (2005)
	Harbor seal *Phoca vitulina concor*	New England, USA	Waring et al. (2006)
	Beluga whale *Delphinapterus leucas*	High Arctic, Canada	Richard et al. (2001)
	Narwhal *Monodon monoceros*	Baffin Island, Canada	Dietz et al. (2001)
	Dugong *Dugong dugon*	Queensland and Northern Territory, Australia	Sheppard et al. (2006)
	California sea lion *Zalophus californianus*	West coast, USA	Weise et al. (2006)
	North Atlantic right whale *Eubalaena glacialis*	Northeast coast, USA	Knowlton et al. (2005)
Habitat use and distribution			
	Beluga whale *Delphinapterus leucas*	Cook Inlet, Alaska, USA	Goetz et al. (2007)
	Gray whale *Eschrichtius robustus*	British Columbia, Canada	Kinzel et al. (2005)
	West Indian manatee *Trichechus manatus*	Georgia and Florida, USA	Reynolds and Haddad (1990)
	Cetaceans	Gulf of Mexico, USA	May et al. (1997)
	Beluga whale *Delphinapterus leucas*	High Arctic, Canada	Barber et al. (2001)
	Bottlenose dolphin *Tursiops truncatus*	South Carolina, USA	Gubbins (2002)
	Southern elephant seal *Mirounga leonina*	Macquarie Island, Australia	Bradshaw et al. (2002)
	Bottlenose dolphin *Tursiops truncatus*	Northwest Atlantic, USA	Torres et al. (2003)
	Cetaceans	All	Redfern et al. (2006)
	Cetaceans	Strait of Gibraltar, Spain	de Stephanis et al. (2008)
	Harbor seal *Phoca vitulina*	Cook Inlet, Alaska, USA	Montgomery et al. (2007)
	Blue whale *Balaenoptera musculus*	Northwest Pacific	Moore et al. (2002)
	Southern elephant seal *Mirounga leonina*	Falkland Islands, UK	Galimberti and Sanvito (1999)
	Australian snubfin dolphin *Orcaella heinsohni*	Great Barrier Reef Marine Park, Queensland, Australia	Parra et al. (2006)
	Indo-Pacific humpback dolphin *Sousa chinensis*	Great Barrier Reef Marine Park, Queensland, Australia	Parra et al. (2006)
	Antarctic fur seal *Arctocephalus gazella*	Cape Noir, Kerguelen Island	Guinet et al. (2001)
	Dugong *Dugong dugon*	Hervey Bay, Queensland, Australia	Sheppard et al. (2007)
Abundance			
	Hawaiian monk seal *Monachus schauinslandi*	Northwestern Hawaiian Islands	Schmelzer (2008)
	Cetaceans	All	de Segura et al. (2007)
	Steller sea lion *Eumetopias jubatus*	Alaska, USA	Fay and Punt (2006)
Assessment of vessel speeds to protect a population			
	Cetaceans	Stellwagen Bank National Marine Sanctuary, Massachusetts, USA	Cowie-Haskell et al. (2005)
	Manatee *Trichechus manatus latirostris*	Florida, USA	Flamm et al. (2001)

Table 1. continued

Application	Species	Location	Reference
Interactions with fisheries			
	Cetaceans, pinnipeds, polar bears	Beaufort Sea, Canada	Muir and Shea (2004)
	Harbor seal *Phoca vitulina*	Norwegian coastline	Bjørge et al. (2002)
	Spotted dolphin *Stenella attenuata*	Eastern Pacific Ocean	Lennert-Cody et al. (2004)
	Spinner dolphin *Stenella longirostris*		
	Common dolphin *Delphinus delphis*		
Monitoring oceanographic features using marine mammals			
	Beluga whale *Delphinapterus leucas*	Svalbard, Sweden	Lydersen et al. (2002)

data have permitted great strides in the research and management of marine mammal diseases. GIS and spatial epidemiology (and analyses) have been used in several applications of marine mammal disease research which will be reviewed.

Mapping

The use of static maps to geographically demonstrate disease (and mortality) events has been in place for many decades in the marine mammal field (Laws and Taylor, 1957). Maps were used to designate the dispersal of a morbillivirus epizootic among harbor seals (*Phoca vitulina*) in northern Europe in 1988 (Dietz et al., 1989; Heide-Jørgensen and Härkönen, 1992). More recently, interactive maps have come into favor in displaying spatiotemporally dynamic disease events [National Marine Fisheries Service, unpublished data]. A further useful tool is mapping of proportions, incidence rates by area, or standardized rates; however, only mapping of proportional deaths of seals due to morbillivirus has been demonstrated in the published marine mammal literature (Härkönen et al., 2006). Harris and Gupta (2006) mapped seal stranding density per 10 km of coastline using stranding data and a GIS to compare stranded seal species and determine predictors of high-seal stranding density, but did not examine actual causes of stranding. Unusual mortality in the depleted (under the US Marine Mammal Protection Act) Cook Inlet beluga whales (*Delphinapterus leucas*) in 2003 was mapped in an effort to help elucidate possible causes of the elevated number of mortalities that year ($n = 20$); however, no further spatial analyses have been performed to date on diseases in this population (Vos and Shelden, 2005). Strandings of pygmy sperm whales (*Kogia breviceps*) were analyzed with a GIS to examine any associations of stranding events with environmental factors (Berini et al., 2007). A significant increase in strandings of this species was noticed during El Niño years.

Surveillance and Monitoring

A GIS can flag geographic areas and populations at risk of unusually high disease occurrence or threat given, for instance, current or projected climatic and environmental factors such as sea surface temperatures or harmful algal blooms. Surveillance and monitoring programs of marine mammal populations provide excellent tools that enable us to help identify baseline patterns of disease occurrence by taxonomic group and presenting syndrome, and to identify disease and stranding knowledge gaps. Spatial analyses of surveillance data can offer baseline patterns against which data on future disease occurrence and patterns can be compared and evaluated for important changes, as well as help identify needed improvements to the data stored in disease databases to make this valuable resource more useful for surveillance purposes in the future (Loth and McKenzie, 2006). The occurrence and prevalence of *Clostridium perfringens* were investigated by analyzing spatial data in order to demonstrate the distribution of the pathogen in sampled polar bears (*Ursus maritimus*), allowing the study of an organism in remote areas in a wild species (Aschfalk et al., 2007). The bottlenose dolphin (*Tursiops truncatus*) Health and Risk Assessment (HERA) project is a comprehensive, multi-disciplinary research program designed to assess environmental and anthropogenic stressors, and health and long-term viability of bottlenose dolphins in coastal estuarine regions of the Indian River Lagoon, Florida (IRL) and Charleston, South Carolina (CSC) (Bossart et al., 2006). As part of the HERA project, dolphin sighting data are being integrated into a GIS in order to link health data collected from live-captures to environmental factors (Adams, 2006), a task that would be virtually impossible without GIS and spatial epidemiology. Exposure of the HERA dolphins to pollutants and other environmental stressors is being spatially analyzed by examining prevalences of disease within each of the subareas of IRL and CSC (Defran et al., 2006; Speakman et al., 2006). Spatial analyses have allowed these researchers to more fully evaluate the possibility of distinct subpopulations, and possibly different environmental exposures, of bottlenose dolphins within IRL and CSC.

Disease Cluster Detection

In epidemiology, a cluster is a group of health events which are located close together in space and/or time and are detected by one or more methods (Moore and Carpenter, 1999). Spatial epidemiology and GIS may be used to predict locations of endemic (multiple cases) and sporadic (single/few cases) clusters of a disease. In Miller et al. (2004), the spatial distribution of stranding location for California sea otters (*Enhydra lutris nereis*) with different *Toxoplasma gondii* genotypes was evaluated using a spatial scan statistic (Kulldorf and Nagarwalla, 1995). Both high- and low-risk clusters were tested against the data. Geographical clustering was identified for strandings caused by leptospirosis, domoic acid, and cancer in California sea lions (*Zalophus californianus*) by using a spatial scan statistic with a Bernoulli model (Kulldorf and Nagarwalla, 1995), and then using these clusters to define additional variables used in logistic regression analyses to identify risk factors for stranding due to leptospirosis (Greig et al., 2005).

Identification of Environmental Predictors of Disease in Wildlife Populations

Maps of disease risk for areas of habitat can be generated and used to identify potential disease "hot spots" or endemic disease. Miller et al. (2002) used spatial data and analyses to evaluate demographic and environmental risk factors for toxoplasmosis in southern sea otters (*Enhydra lutris nereis*). Of particular interest was proximity of live sea otter sampling sites to the nearest major municipal sewage outfall sites along the coast. Quantification of outflow was accomplished with a GIS along with an exponential dilution model to predict the influence of runoff from rivers and streams on watersheds. In addition, the spatial relationship between *Toxoplasma gondii* serological status in sea otters and live-sampling location was analyzed using SaTScan, version 2.1 (http://www.nic.nih.gov/prevention/bb/satscan.html). Environmental risk factors for leptospirosis in California sea lions during a 2004 epizootic in California were explored with spatial epidemiology and a GIS, in Norman et al. (in press). Stranding locations of both cases and non-cases were overlayed onto spatial environmental data layers such as freshwater hydrographic units, dog park locations, and county cattle density in order to analyze differences between cases and non-cases in regard to various suspected environmental risk factors for leptospirosis. For instance, the stranding and dog park layer were overlayed, and a spatial analyst tool (Hawth's Analysis Tools for ArcGIS; http://www.spatialecology.com) was used to calculate the nearest distance between a sea lion stranding location and a dog park. The resulting distance was used as an environmental variable in a multivariate logistic regression modeling assessing the association (presented as odds ratios) between risk factors and leptospirosis.

Risk Assessment

Risk assessments have been used as qualitative or quantitative evaluations of the environmental and/or health risks resulting from exposure to a chemical or physical agent such as a disease. Risk assessments have been used extensively in human health management and terrestrial mammals, and can be expanded to include marine mammal health investigations. While few risk assessments have been conducted on marine mammals, a small number have been carried out on contaminant levels in discrete populations of animals. For example, the risk associated with consumption of contaminated prey items in the Indo-Pacific Humpback dolphin (*Sousa chinensis*) near potential sources of pollution in urbanized Hong Kong waters was analyzed (Hung et al., 2004, 2007). In addition, assessments have been conducted to quantify the risk of mortality due to fishery interactions in cetaceans (Slooten et al., 2000). Examples of risk assessments of marine mammal diseases were not found in the published literature.

Modeling Spread and Impact of Disease in Marine Mammals and the Oceans

Emerging infectious diseases in marine mammals introduce a host of novel, complex conservation problems, particularly due to conflicts arising between the conservation of biodiversity, and actual or perceived threats to public health or domestic species (Harvell et al., 1999; Scholin et al., 2000).

The use of marine model systems for environmental health-related research, for instance, may serve as a surrogate for the study of environmentally related pathological states (Contreras et al., 2006). This research could further the development of models and risk assessments to assess potential detrimental anthropogenic and environmental impacts on marine mammals. In developing predictive models, it must be kept in mind that disease spread rates are much faster in the ocean, and that the ocean is generally a more open system with fewer barriers to long-distance dispersal, therefore offering a greater potential for pathogens to survive long periods outside a host or in secondary hosts (McCallum et al., 2004). It is imperative to collect data to gain insight into the epidemiology of these marine diseases so that conservation projects can be developed to ensure the survival of marine mammal species. Most disease studies in marine mammals have focused on description of signs and pathology with some diagnostic testing (e.g., culture, isolation, immunohistochemistry). Very few publications have included epidemiology, much less spatial epidemiology, and mathematical disease modeling.

Recent developments in the use of GIS for analysis of spatial epidemiologic data in humans and terrestrial wildlife have taken place for detecting spatial and/or temporal disease clusters, estimating disease exposure levels in unsampled locations (Lawson et al., 1999) and in modeling and estimating disease risk factors through empirical Bayesian or generalized linear mixed models (GLMMs) (Ostfeld et al., 2005). Within the marine mammal research field, the use of Bayesian statistics and GLMMs has been limited to characterizing habitats and abundance estimates (Moore, 2005; Fay and Punt, 2006). The incorporation of hierarchical Bayesian modeling, for example, could be used to account for extra-sample variation of marine mammal surveillance data, and spatial and temporal clustering.

Challenges of Applying Spatial Epidemiology and GIS to Marine Mammal Conservation Medicine

Several challenges and limitations come to light when applying spatial epidemiology and GIS to marine mammal conservation. Some of these limitations may be addressed quite readily, but others may require further research and development to refine the application. First, it is logistically difficult (or impossible) to routinely sample most wild marine mammal species, even opportunistically, further complicating the effort to standardize data collection and integration of disease data to form reliable disease baselines. Second, due to wide-ranging movements and habitats for many species, more sophisticated statistical techniques are needed to account for animal movement in disease dynamics, such as kernel density estimators, which have been applied recently to terrestrial wildlife (Seaman and Powell, 1996; Conner and Miller, 2004), but have not yet been applied to marine mammal disease studies. Third, the inability to even identify most causative agents and the lack of standard epidemiological disease data for most marine mammal populations can potentially limit the ability to examine host–pathogen interactions, to analyze changes in disease dynamics, and to assess the impact of diseases on host populations and associated communities in the world's oceans. There is a lack of basic information needed to study and predict the presence and impact of diseases on marine mammals. The ability to regularly diagnose, characterize, and interpret diseases is poor compared to humans and terrestrial animals. Fourth, strengthening interdisciplinary studies of marine diseases is critical, focusing on the development of better molecular and computational tools, and understanding mechanisms of disease resistance in marine organisms. Fifth, there are few labs with expertise in analyzing and interpreting marine mammal biological samples. Lastly, in an attempt to apply terrestrial epidemiological methods (particularly spatial epidemiology) to ocean systems, one must keep in mind that marine systems are qualitatively different from the terrestrial environment, so this can affect modeling and management approaches (McCallum et al., 2004). Marine organisms likely have different disease transmission modes than their terrestrial counterparts and live in more open populations, so the potential for long-distance dispersal of pathogens exists, which might enable unusually rapid propagation of epizootics in marine systems. Therefore, new approaches to modeling and control of diseases in the marine environment must be developed (McCallum et al., 2004).

Recommendations for Future Research Efforts in Spatial Epidemiology and GIS

1. Improve standardized collection of spatial marine mammal disease data for developing baseline information such as serology, bacterial and viral cultures, parasite identification, and pollution levels.
2. Development of more centralized geospatial processing units that have substantial flexibility and analytical capabilities for spatial analyses and risk assessments specific to marine mammal diseases.
3. Further multidisciplinary collaborations between marine mammal veterinarians, epidemiologists, disease ecologists, biologists, and statisticians to enhance collection, analysis, and interpretation of georeferenced data in the context of disease studies.
4. Identify qualified individuals, organizations, and agencies to conduct marine mammal disease modeling and further develop appropriate epidemiologic study designs and spatial analytic techniques.
5. Better utilize existing marine mammal population and environmental databases to link to disease databases, for use in epidemiologic studies.

Conclusion

Since location is an integral part of investigating disease, spatial epidemiology and GIS should, and probably must, be incorporated as a data management and analysis tool in the study of marine mammal diseases and conservation medicine. These tools can make wildlife health information easier to record, disseminate, share, and analyze. Spatial epidemiology and GIS can help marine mammal conservation medicine by providing reliable information about the presence of a species, its prey, diseases, habitat, and threats to population viability. The individual involved in marine mammal conservation medicine can use spatial epidemiology and GIS technology to map important marine mammal diseases to identify known distribution of pathogens including morbillivirus, leptospirosis, and brucella. Information gaps along coastlines can be identified, and agency managers provided with disease databases that extend across jurisdictional boundaries. More importantly, these tools provide health professionals a method of evaluating ecological health, human and animal health, habitat quality, food supply, and the physical environment when practicing conservation medicine.

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