10-1-2015

Connecting Disease with the Enviornment:what can multidisciplinary science do for Epidemiology?

Amanda Jamison
Indiana State University

Literature Review for GEOG700

Connecting Disease with the Environment: What Can Multidisciplinary Science do for Epidemiology?

Amanda Jamison

Abstract

With the resurgence of disease in many parts of the world, many aspects of treatment and prevention are of great interest to researchers. A common approach to deter disease is the prevention or control of vectors. Movement of viruses and microscopic pathogens into new habitat, through accidental introduction or range expansion is therefore of great interest. While research in the biological sciences and ecology have revealed important life history of hosts and medical applications, other aspects need to be explored to understand vector biology and transmission. As arthropod vectors are dependent on environmental factors, research into geographic information systems may be a useful tool, as the recent advances in technology can collect ecological data with greater precision and accuracy than ever before. Many studies have begun to examine the potential applications of geospatial technology, while integrating typical ecological components. Here we review the previous work in multidisciplinary research incorporating climate, geographic information systems and vector ecology. Scientists collaborate from various aspects of biology and climatology ranging from connecting local weather conditions and climate to large scale teleconnections and the creation of continent wide climate boundaries, climate envelopes or models. Suggestions for the future directions of combining these disciplines are discussed.

Introduction

The advent of rapidly changing technology in the last century has implications across many disciplines as computer hardware and programs are not only accessible to researchers outside computer science and engineering, but affordable. Scientists have incorporated advanced technology into their research across multiple disciplines within life and physical sciences allowing for data collection with greater sophistication, sensitivity, and accuracy. The creation of geographic information science from the advent of technological research has brought forth specializations for the purpose of finding applications in multidisciplinary studies, using geographic information systems (GIS) (Clarke, McLafferty and Tempalski 1996, Goodchild 1992). This science has been incorporated into many different aspects for spatial analysis, collecting data at large scales previously not possible in other disciplines. This geospatial technology is a potentially powerful tool in biological and ecological studies (Roughgarden, Running and Matson 1991, Dominy and Duncan 2002, Aplin 2005). Recent investigations into remote sensing applications to detect changes in habitat or environmental conditions have developed methods for a wide range of biological and ecological questions (Broadbent et al. 2008, Chambers et al. 2007, Nair et al. 2008, Valavanis et al. 2008, Formica et al. 2004, Kalluri et al. 2007). Past expenditures have been relegated to large scale investigations but with the progress in technology, even smaller scales, 1 m^2 or less can be explored with incorporated remote sensing (Mumby and Edwards 2002, Tanaka and Sugimura 2001, Birk et al. 2003, Roughgarden et al. 1991). With the advent of information technology abundance, multidisciplinary research can be explored in further depth to answer many ecological questions. One problem is the effects of changes in global climate and the ecological consequences (Patz and Olson 2006, Roessig et al. 2004, Purse et al. 2005). Therefore, it is of interest for biologists and ecologists to collaborate with physical sciences to reveal the role of climate in ecosystems and on organismal biology. Particular interest in disease distribution and climate is prevalent since climate change may increase the range of many debilitating illnesses in humans and livestock (Githeko et al. 2000, Purse et al. 2005). Here we review the previous work in multidisciplinary research incorporating climate, geographic information systems and vector biology and discuss some of the research incorporating GIS and climate in ecology and suggest future directions for climatology and ecological research.

Geospatial technology and techniques have greatly improved over the last decade resulting in the ability of satellites and aerial platforms to record and produce data at finer resolutions and scales than previously, compared to on the ground measurements. Satellite data can detect reflectance of electromagnetic radiation at resolutions at one meter or less from commercial sources (Mumby and Edwards 2002, Read et al. 2003, Birk et al. 2003) and be applied to various anthropomorphic applications (Zomeni, Tzanopoulos and Pantis 2008, Seelan et al. 2003, Narumalani, Mishra and Rothwell 2004, Zhu et al. 2005, Smith and Thomson 2003), reveal global and local changes from disturbance to disasters (Ramsey, Chappell and Baldwin 1997, Myint et al. 2008, Potter et al. 2003, Ledrew 1992, Nemani and Running 1995) and support evidence for global climate change (Stow et al. 2004, Rosenqvist et al. 2003, Hinzman et al. 2005, Silapaswan, Verbyla and McGuire 2001, Masek 2001, Simas, Nunes and Ferreira 2001). These have been used to predict environmental variables, or connect changes in the environment to biological patterns from food availability (Wilmers and Post 2006), habitat quality (Wiegand et al. 2008, Valavanis et al. 2008), movement (Chapman, Reynolds and Smith 2003) and abundance or outbreak of insects (Hurley et al. 2004, Reisig and Godfrey 2006). However, the connections between climate and vector biology are more tenuous. Much work on the connections between biology and geography focus on ecology, where typical ecological measurements are used and compared with disease prevalence. Various single environmental measurements in ecology have connected changes in animal life history or biodiversity, such as temperature and rainfall, (Barrientos et al. 2007, Li and Brown 1999, Lysyk and Danyk 2007), while others connect to extreme events occurred after El Niño (Perriman et al. 2000), including disease outbreaks (Yang and Scherm 1997, Ward and Johnson 1996). Commonly in epidemiology studies researchers draw connections between aspects of climate: precipitation and temperature with abundance and/or disease outbreak. Population cycles of red grouse heavily connected to parasitic infection has population cycles could be controlled by treating infections (Hudson, Dobson and Newborn 1998) and had parasite dominated population cycles predicted by climate-parasite models, based on the amount of precipitation and temperature (Cattadori, Haydon and Hudson 2005) and similarly cholera has found to cycle with climatic factors including ENSO (Pascual et al. 2000). Connecting disease and the environment be it ecological or climatic aspects, has lead an effort into finding ways of incorporating new technology to find hot spots, or areas of potential outbreak, at risk regions (Clarke et al. 1991). While previously mentioned parasites lacks an animal vector many diseases need an accomplice to actively spread, often leading researchers to examine the life sciences of vector transmission.

While many diseases can be acquired from another host or via the environment, many are transmitted by biological vectors. It follows that vector ecology is explored as an indirect explanation of disease cycles, outbreaks, and prevalence. Many of these vectors are arthropods (Phylum *Arthropod*a) and include ticks, fleas, mosquitoes, black flies, and biting midges (see Table 1, Valkiūnas 2005, Fallis and Bennett 1961, Barbour and Fish 1993, Kiszewski and Cupp 1986, Durden and Page 1991, Mellor, Boorman and Baylis 2000). Many Dipteran insects (includes the families *Cuculidae*: mosquitoes, *Simuliidae*: black flies, and *Ceratopogonidae*: biting midges) require a minimum temperature and moisture content in order to successfully cycle through their various instar larva stages (Adler, Currie and Wood 2003, Darsie and Ward 2005, Focks et al. 1993, Mellor et al. 2000). Therefore detecting or modeling levels of precipitation and temperature may successfully predict insect outbreaks and current and/or possible expansion of disease range(s) (Purse et al. 2005, Cook et al. 1998, Lindsay, Parson and Thomas 1998, Ward 1996). The ability to prevent or predict the next epidemic is particularly important in developing countries with populations that experience the highest rates of infection, and the lack of medicinal resources (Barat et al. 2004) and resistance of vectors to pesticides and disease to medication (Greenwood and Mutabingwa 2002, Lenormand et al. 1999, Montagna et al. 2003). Moreover, changes in ecosystems as consequence or in conjunction with climate changes, may explain the changes we see in disease across the world, and is important to consider in epidemiology and vector ecology (Barbour and Fish 1993, Harrus and Baneth 2005, Sallares 2006).

Family: *Culicidae* - Mosquitoes

Changes in moisture or precipitation are common ecological and meteorological factors considered when predicting mosquito abundance. Mosquito species are of great concern worldwide as they can spread many diseases ranging from unicellular protists, (i.e. malaria) to viruses (e.g. Dengue fever, Yellow fever, and West Nile Virus (encephalitis)) that affect human populations (Goddard 1998, Khaemba, Mutani and Bett 1994, Vanderberg and Gwadz 1980, Kulasekera et al. 2001, Romero-Vivas, Leake and Falconar 1998). Since their ability to reproduce is directly related to environmental factors including the presence of still water, this is often explored when considering disease detection methods. As abundance of mosquitoes depends on available water sources and precipitation researchers correlate this directly with infections (Focks et al. 1993, Koella, Agnew and Michalakis 1998, Mabaso et al. 2007, Singh and Sharma 2002, Kelly-Hope, Purdie and Kay 2004), and use these ecological parameters in models (Schaeffer, Mondet and Touzeau 2008a, Schaeffer, Mondet and Touzeau 2008b, Hopp and Foley 2003, Zhou et al. 2004) despite contradicting evidence (Shanks et al. 2002). Often remote sensing is used to detect the presence of moisture or water in the environment using vegetation indices such as NDVI (Normalized Differential Vegetation Index) that correlate with vegetation in arid environments and these studies can incorporate climatic aspects as well confirming the intuitive concept of increased temperature and rain preceding mosquito and disease outbreaks (Rogers et al. 2002, Stockli and Vidale 2004, Duchemin et al. 2006, Kawamura et al. 2005, Gleiser, Gorla and Almeida 1997, Pope et al. 1994, Brown et al. 2008). Additionally, these indices connect disease and mosquito vectors creating predictive models that substantiate the environmental changes with disease (Hay, Snow and Rogers 1998, Rogers et al. 2002, Cuevas et al. 2007, Anyamba et al. 2002, Zhou et al. 2004) and with projected increases in temperature may relay important information about the spread of vectors and disease (Reiter 2001) and the creation of risk maps (Kitron 2000). However, vegetation indices may reflect soil moisture and plant productivity, but not necessarily still water or temperature required for mosquito reproduction. As vegetation indices reach an asymptote distribution, saturation occurs with dense foliage (Liu and Huete 1995, Huete et al. 2002) making the use of NDVI appropriate in arid and strongly seasonal ecosystems, but not necessarily humid ones or for landscape with dense forest. Climatic data from the field may be a better representation in conjunction with different remote sensing techniques such as the Enhanced Vegetation Index (EVI) or the water index (NDWI Normalized Differential Water Index) (Gao 1996, Liu and Huete 1995, Huete et al. 2002), as mosquitoes in North America have varied with temperature and precipitation (Reisen et al. 2008, Britch et al. 2008), experienced community changes (Britch et al. 2008), as well as extreme events in oscillations (Heft and Walton 2008) in addition to mosquito populations in tropical areas (Chadee et al. 2007, Graves et al. 2008, Mabaso et al. 2007, Gagnon, Smoyer-Tomic and Bush 2002).

Family: *Ceratopogonidae* – Biting Midges

Similar to mosquitoes, only female biting midges (Diptera: *Ceratopogonidae*) seek a blood meal and transmit diseases, many which infect wild animals or livestock (Mellor et al. 2000, Marquardt and Kondratieff 2005) and may be correlated with climate. Biting midge populations may not be clearly indicated by remote sensing which is used to indirectly estimate climatic variables (Kalluri et al. 2007, Han et al. 2005, Crombie et al. 1999), as it difficult to study this group based on their immensely small size of a millimeter or more and that their breeding grounds range greatly including still water, moist soil, rotting vegetation, and others based on the species (Mellor et al. 2000, Blackwell, Young and Mordue 1994). Despite these challenges, remote sensing techniques and ecology have been used to connect habitat, dispersal, and potential effects of climate change on the vector species (Purse et al. 2005, Baylis et al. 1998). The biting midge as a vector often has been investigated to predict the spread of Bluetongue virus (BTV) using remote sensing and climate, where NDVI is used to represent soil moisture in Africa (Purse et al. 2004, Baylis et al. 1998). Ecological studies incorporate different meteorological and climate aspects and revealed the ability of biting midges to disperse and consequently spread disease with wind conditions, with vectors estimated to travel at 1km in altitude and transported across countries, such as outbreaks in Israel and Florida, previously not exposed to BTV through unusual wind events (in the Intertropical Convergence Zone or Persian air trough system) (Braverman and Chechik 1996, Sellers and Maarouf 1991, Blackwell 1997, Sellers and Maarouf 1989, Sellers 1980). Other aspects of limitations may include rainfall, or summer temperature, but do not always find clear connections and suggest that long term patterns over large scale areas may be understood by investigating climate and its resulting local weather conditions (Braverman and Chechik 1996, Blackwell 1997, Braverman, Chechik and Mullens 2001, Ortega, Holbrook and Lloyd 1999, Rawlings et al. 1998, Ward 1996, Conte et al. 2003). While climate envelope models accurately cover areas of BTV outbreak, these build a premise for involving climate change and vector ecology and have depicted the movement of Blue tongue Virus into Europe and accurately predict range expansion with climate change (Purse et al. 2007, Purse et al. 2005, Purse et al. 2004, Calistri et al. 2003). While Baylis et al. (Baylis, Mellor and Meiswinkel 1999) suggests that ENSO may play a role in the spread of AHS, very little has been done to research how large scale climatic patterns (for example teleconnections like NAO, PNA, etc.) influence vector ecology of this group, which may be particularly important as biting midges are susceptible to wind and rain conditions (Blackwell 1997, Sellers 1980, Rawlings et al. 1998). Further work should explore the various major aspects of climate and meteorology as they may explain dispersal, outbreak patterns, as well as changes in their ecology.

Family *Simuliidae*: - Black Flies

The ecology of black flies is similar to its sister families in that they use running water for breeding grounds, but have not been investigated in the same extensiveness as a vector in multidisciplinary research. Members of this family can harbor parasites and, ranging from malarial type parasites (*Leucocytozoon*), Trypanosomes, and filarial nematodes in birds, to stomatitis virus serotypes and nematodes for mammals (Marquardt and Kondratieff 2005, Hunter, Rohner and Currie 1997, Kiszewski and Cupp 1986, Reeves et al. 2007), but are mainly a nuisance to people by their blood seeking behavior, causing loss of tourism in black fly breeding areas (Marquardt and Kondratieff 2005, Metcalf 1932). This has instigated the use of pesticides which have eliminated some competent vectors, but may promote resistance, when other ecological controls could suffice (Cheke et al. 2008, Adler et al. 2003, Metcalf 1932, Rivers-Moore, Hughes and de Moor 2008, Lenormand et al. 1999, Montagna et al. 2003). While there is research into the capacity of black flies in North America to transmit vesicular stomatitis virus to domesticated animals, there is a lack of information on their vector ecology and how environmental factors will influence their transmission, despite outbreaks infections of nematode *Onchocerca volvulus* in humans, which have prompted control programs (Pinto et al. 2008, Mead, Mare and Cupp 1997, Schmidtmann et al. 1999, Mead et al. 2004, Marquardt and Kondratieff 2005, Basanez et al. 1996, Shelley and Coscaron 2001, Hougard et al. 1997). Vesicular stomatitis virus outbreaks in the late 1990s in North America were preceded by precipitation and known competent vectors are present suggests that blackfly microclimate may be important for detection and modeling (McCluskey, Beaty and Salman 2003, Mead et al. 1997, Mead et al. 2004). Ecological researchers highlight the importance of stream conditions and flow rates, on larval populations for control methods and the importance of meteorological or microclimate conditions for adult activity levels, where vapor pressure, wind speed, and temperature are highly important (Rivers-Moore et al. 2008, Shipp, Grace and Schaalje 1987, Shipp, Grace and Janzen 1988, Grillet and Barrera 1997, Lounaci et al. 2000, Fredeen and Mason 1991). Some preliminary and antidotal work on black fly populations involving climate factors such as rainfall, flooding from El Niño events and seasonality with population numbers have been recorded (Everitt et al. 1994, Cilek and Schaediger 2004, Grillet et al. 2001, Grillet and Barrera 1997) but there is a lack of multidisciplinary research including climatic aspects as this species does not have a known large health impact on human populations.

Ticks and others

Vectors are not limited to the previous dipteran flies as many well known diseases such as Lyme disease are carried in ticks (Order Ixodida), while tsetse flies (Diptera: *Muscidae*) transmit sleeping sickness and kissing bugs (Hemiptera: *Reduviidae*) Chagas disease (Trypanosome spp.) to humans in addition to other animals (Barrett et al. 2003, Marquardt and Kondratieff 2005, Killilea et al. 2008). These various organisms are dependent on various microhabitat conditions and ecological factors similar to other arthropods, but ticks being the only non-insects may need a different focus (Randolph 1998). The reforestation of parts of the United States and the population boom of deer has boosted the spread of Lyme disease across the country (via deer and other ticks) and has fuelled a great interest in spatial analysis and prevention methods (Barbour and Fish 1993, Killilea et al. 2008). Distribution of ticks are of great interest in North America and Europe due to the high rates of Lyme disease and encephalitis infection and are studied in several environmental aspects, ranging from landscape ecology, seasonality, and climate (Rodgers, Miller and Mather 2007, Lindgren, Talleklint and Polfeldt 2000, Eisen et al. 2003). Such studies that incorporate climatic aspects, such as precipitation and soil moisture may successfully integrate tick abundance with disease risk in North America (Rodgers et al. 2005, Barbour and Fish 1993) as nymph stages of this vector depend on soil moisture and humidity (Rodgers, Zolnik and Mather 2007). Correlates with drought or moisture index and temperature have been observed with tick numbers on the U.S. east coast in Black-legged ticks (Subak 2003) and with vegetation indices (Rodgers et al. 2005), but not for all regions (Ostfeld et al. 2006). Using remote sensing and climate, predicting expansion of tick ranges, and consequently Lyme disease through climate change can be incorporated into risk maps important for public health planning and awareness (Ogden et al. 2008). Other vectors have been investigated similarly with aspects of ecology and climate for vector abundance in areas of high transmission including sand flies (Diptera: *Psychodidae*), tsetse (Diptera: *Muscidae*), and as their life cycles are similarly dependent on moisture and have been explored using remote sensing (Salomon et al. 2004, Hendrickx et al. 2001). However, as most arthropod vectors are insects treating ticks the same as these taxa may not be accurate and researchers should consider their differences in life history and ecology when creating risk maps and projections with climate changes (Randolph 1998).

<u>Climate Change</u>

IPCC and researchers have postulated the major changes in climate within the last century and future changes to have drastic actions, primarily in increasing temperature and intensity of weather events (Meehl et al. 2000). Predictions of human induced climate change of global warming and increases in frequency of extreme events do not bode well for wildlife and plants as numerous observations of species responses have shown phenological and ecological changes, even decline and extinction based on observations over the last 50 years (Mitchell et al. 2006, Parmesan 2006, Winkler, Dunn and McCulloch 2002). Future populations may suffer if unable to adapt to these climatic changes quickly and shrinking ranges and extinctions are expected (Thomas, Franco and Hill 2006). Forecasts of disease however, predict range expansion in terms of changes in latitude and altitude with the increase in temperature and changes in vector competency. As insects are ectotherms, the external temperature heavily influences their biology and environment for disease development, leading to potential increase in vector competence (Reiter 2001, Reeves et al. 1994). The possibility for not only the spread of disease through range expansion, but the addition of new vectors may have drastic effects on ecosystems, human health, and the global community (Purse et al. 2005, Epstein et al. 1998, Reiter 2001). As climate changes are to be excessively more dramatic, concerns over weather events and disasters will be need to be explored in further detail for patterns as to the role they play in ecosystems globally.

Summary

Investigations into the ecology of vectors has focused mainly on microhabitat and eradication or control efforts as their impact on human health and economy across the world remains significant (Patz and Olson 2006, Gallup and Sachs 2001, Singh et al. 2004). Climatic aspects have been used to predict range changes, expansion, and disease outbreak patterns incorporating technology in GIS and remote sensing and correlating with field data. However, aspects of animal life history, and ecological interactions are not considered such as nutrient cycling and its effects of changes in insect microhabitat, in addition to compounded factors of climate changes (McKenzie and Townsend 2007). Limited amount of study has included complex and long term climate data and those that incorporate teleconnections may be antidotal (i.e. Cilek and Schaediger 2004, Sellers and Maarouf 1989). The complex relationships in ecology will need to consider not only vector biology and weather measurements, but take into account appropriate scales and covarying factors. Future projects need to incorporate multidisciplinary collaborations to ensure that appropriate measures and factors are considered with ecological interactions, as they vary across the globe.

Literature Cited:

Adler, P. H., D. C. Currie & D. M. Wood. 2003. *The Black Flies (Simuliidae) of North America*. Ithaca: Cornell University Press.

Anyamba, A., K. J. Linthicum, R. Mahoney, C. J. Tucker & P. W. Kelley (2002) Mapping potential risk of Rift Valley fever outbreaks in African savannas using vegetation index time series data. *Photogrammetric Engineering and Remote Sensing,* 68**,** 137-145.

Aplin, P. (2005) Remote sensing: ecology. *Progress in Physical Geography,* 29**,** 104-113.

Barat, L. M., N. Palmer, S. Basu, E. Worrall, K. Hanson & A. Mills (2004) Do malaria control interventions reach the poor? A view through the equity lens. *American Journal of Tropical Medicine and Hygiene,* 71**,** 174-178.

Barbour, A. G. & D. Fish (1993) THE BIOLOGICAL AND SOCIAL PHENOMENON OF LYME-DISEASE. *Science,* 260**,** 1610-1616.

Barrett, M. P., R. J. S. Burchmore, A. Stich, J. O. Lazzari, A. C. Frasch, J. J. Cazzulo & S. Krishna (2003) The trypanosomiases. *Lancet,* 362**,** 1469-1480.

Barrientos, R., A. Barbosa, F. Valera & E. Moreno (2007) Temperature but not rainfall influences timing of breeding in a desert bird, the trumpeter finch (Bucanetes githagineus). *Journal of Ornithology,* 148**,** 411-416.

Basanez, M. G., H. Townson, J. R. Williams, H. Frontado, N. J. Villamizar & R. M. Anderson (1996) Density-dependent processes in the transmission of human onchocerciasis: Relationship between microfilarial intake and mortality of the simuliid vector. *Parasitology,* 113**,** 331-355.

Baylis, M., H. Bouayoune, J. Touti & H. El Hasnaoui (1998) Use of climatic data and satellite imagery to model the abundance of *Culicoides imicola*, the vector of African horse sickness virus, in Morocco. *Medical and Veterinary Entomology,* 12**,** 255-266.

Baylis, M., P. S. Mellor & R. Meiswinkel (1999) Horse sickness and ENSO in South Africa. *Nature,* 397**,** 574-574.

Birk, R. J., T. Stanley, G. I. Snyder, T. A. Hennig, M. M. Fladeland & F. Policelli (2003) Government programs for research and operational uses of commercial remote sensing data. *Remote Sensing of Environment,* 88**,** 3-16.

Blackwell, A. (1997) Diel flight periodicity of the biting midge *Culicoides impunctatus* and the effects of meteorological conditions. *Medical and Veterinary Entomology,* 11**,** 361-367.

Blackwell, A., M. R. Young & W. Mordue (1994) THE MICROHABITAT OF *CULICOIDES-IMPUNCTATUS* (DIPTERA, CERATOPOGONIDAE) LARVAE IN SCOTLAND. *Bulletin of Entomological Research,* 84**,** 295-301.

Braverman, Y. & F. Chechik (1996) Air streams and the introduction of animal diseases borne on Culicoides (Diptera, Ceratopogonidae) into Israel. *Revue Scientifique Et Technique De L Office International Des Epizooties,* 15**,** 1037-1052.

Braverman, Y., F. Chechik & B. Mullens (2001) The interaction between climatic factors and bluetongue outbreaks in Israel and the eastern Mediterranean, and the feasibility of establishing bluetongue-free zones. *Israel Journal of Veterinary Medicine,* 56**,** 99-109.

Britch, S. C., K. J. Linthicum, A. Anyamba, C. J. Tucker, E. W. Pak & T. Mosquito Surveillance (2008) Long-term surveillance data and patterns of invasion by *Aedes albopictus* in Florida. *Journal of the American Mosquito Control Association,* 24**,** 115-120.

Broadbent, E. N., G. P. Asner, M. Keller, D. E. Knapp, P. J. C. Oliveira & J. N. Silva (2008) Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. *Biological Conservation,* 141**,** 1745-1757.

Brown, H. E., M. A. Diuk-Wasser, Y. Guan, S. Caskey & D. Fish (2008) Comparison of three satellite sensors at three spatial scales to predict larval mosquito presence in Connecticut wetlands. *Remote Sensing of Environment,* 112**,** 2301-2308.

Calistri, P., M. Goffredo, V. Caporale & R. Meiswinkel (2003) The distribution of Culicoides imicola in Italy: Application and evaluation of current Mediterranean models based on climate. *Journal of Veterinary Medicine Series B-Infectious Diseases and Veterinary Public Health,* 50**,** 132-138.

Cattadori, I. M., D. T. Haydon & P. J. Hudson. 2005. Parasites and climate synchronize red grouse populations. In *Nature*, 737-741. Nature Publishing Group.

Chadee, D. D., B. Shivnauth, S. C. Rawlins & A. A. Chen (2007) Climate, mosquito indices and the epidemiology of dengue fever in Trinidad (2002-2004). *Annals of Tropical Medicine and Parasitology,* 101**,** 69-77.

Chambers, J. Q., G. P. Asner, D. C. Morton, L. O. Anderson, S. S. Saatch, F. D. B. Espirito-Santo, M. Palace & C. Souza (2007) Regional ecosystem structure and function: ecological insights from remote sensing of tropical forests. *Trends in Ecology & Evolution,* 22**,** 414-423.

Chapman, J. W., D. R. Reynolds & A. D. Smith (2003) Vertical-looking radar: A new tool for monitoring high-altitude insect migration. *Bioscience,* 53**,** 503-511.

Cheke, R. A., G. K. Fiasorgbor, J. F. Walsh & L. Yameogo (2008) Elimination of the Djodji form of the blackfly *Simulium sanctipauli sensu stricto* as a result of larviciding by the WHO Onchocerciasis Control Programme in West Africa. *Medical and Veterinary Entomology,* 22**,** 172-174.

Cilek, J. E. & J. F. Schaediger (2004) Regional occurrence of a severe infestation of *Simulium slossonae* (Diptera : Simuliidae) associated with an El Nino event in Florida. *Florida Entomologist,* 87**,** 169-172.

Clarke, K. C., S. L. McLafferty & B. J. Tempalski (1996) On epidemiology and geographic information systems: A review and discussion of future directions. *Emerging Infectious Diseases,* 2**,** 85-92.

Clarke, K. C., J. P. Osleeb, J. M. Sherry, J. P. Meert & R. W. Larsson (1991) THE USE OF REMOTE-SENSING AND GEOGRAPHIC INFORMATION-SYSTEMS IN UNICEFS DRACUNCULIASIS (GUINEA WORM) ERADICATION EFFORT. *Preventive Veterinary Medicine,* 11**,** 229-235.

Conte, A., A. Giovannini, L. Savini, M. Goffredo, P. Calistri & R. Meiswinkel (2003) The effect of climate on the presence of *Culicoides imicola* in Italy. *Journal Of Veterinary Medicine. B, Infectious Diseases And Veterinary Public Health,* 50**,** 139-147.

Cook, T., M. Folli, J. Klinck, S. Ford & J. Miller (1998) The relationship between increasing sea-surface temperature and the northward spread of Perkinsus marinus (Dermo) disease epizootics in oysters. *Estuarine Coastal and Shelf Science,* 46**,** 587-597.

Crombie, M. K., R. R. Gillies, R. E. Arvidson, P. Brookmeyer, G. J. Weil, M. Sultan & M. Harb (1999) An application of remotely derived climatological fields for risk assessment of vector-borne diseases: A spatial study of filariasis prevalence in the Nile delta, Egypt. *Photogrammetric Engineering and Remote Sensing,* 65**,** 1401-1409.

Cuevas, L. E., I. Jeanne, A. Molesworth, M. Bell, E. C. Savory, S. J. Connor & M. C. Thomson (2007) Risk mapping and early warning systems for the control of meningitis in Africa. *Vaccine,* 25**,** A12-A17.

Darsie, R. F. & R. A. Ward. 2005. *Identification and Geographical Distribution of the Mosquitos of North America, north of Mexico*. Gainesville: University Press of Florida.

Dominy, N. J. & B. Duncan (2002) GPS and GIS methods in an African rain forest: Applications to tropical ecology and conservation. *Conservation Ecology,* 5**,** 13.

Duchemin, B., R. Hadria, S. Erraki, G. Boulet, P. Maisongrande, A. Chehbouni, R. Escadafal, J. Ezzahar, J. C. B. Hoedjes, M. H. Kharrou, S. Khabba, B. Mougenot, A. Olioso, J. C. Rodriguez & V. Simonneaux (2006) Monitoring wheat phenology and irrigation in Central Morocco: On the use of relationships between evapotranspiration, crops coefficients, leaf area index and remotely-sensed vegetation indices. *Agricultural Water Management,* 79**,** 1-27.

Durden, L. A. & B. F. Page (1991) ECTOPARASITES OF COMMENSAL RODENTS IN SULAWESI UTARA, INDONESIA, WITH NOTES ON SPECIES OF MEDICAL IMPORTANCE. *Medical and Veterinary Entomology,* 5**,** 1-7.

Eisen, R. J., L. Eisen, M. B. Castro & R. S. Lane (2003) Environmentally related variability in risk of exposure to Lyme disease spirochetes in northern California: Effect of climatic conditions and habitat type. *Environmental Entomology,* 32**,** 1010-1018.

Epstein, P. R., H. F. Diaz, S. Elias, G. Grabherr, N. E. Graham, W. J. M. Martens, E. Mosley-Thompson & J. Susskind (1998) Biological and physical signs of climate change: Focus on mosquito-borne diseases. *Bulletin of the American Meteorological Society,* 79**,** 409-417.

Everitt, J. H., D. E. Escobar, K. R. Summy & M. R. Davis (1994) USING AIRBORNE VIDEO, GLOBAL POSITIONING SYSTEM, AND GEOGRAPHICAL INFORMATION-SYSTEM TECHNOLOGIES FOR DETECTING AND MAPPING CITRUS BLACKFLY INFESTATIONS. *Southwestern Entomologist,* 19**,** 129-138.

Fallis, A. M. & G. F. Bennett (1961) Ceratopogonidae as Intermediate Hosts for *Haemoproteus* and Other Parasites. *Mosquito News,* 21**,** 21-28.

Focks, D. A., D. G. Haile, E. Daniels & G. A. Mount (1993) Dynamic Life Table Model for *Aedes aegypti* (Diptera: Culicidae): simulation results and validation. *Journal of Medical Entomology,* 30**,** 1018-1028.

Formica, V. A., R. A. Gonser, S. Ramsay & E. M. Tuttle (2004) Spatial dynamics of alternative reproductive strategies: the roles of neighbors. *Ecology,* 85**,** 1125-1136.

Fredeen, F. J. H. & P. G. Mason (1991) METEOROLOGICAL FACTORS INFLUENCING HOST-SEEKING ACTIVITY OF FEMALE *SIMULIUM-LUGGERI* (DIPTERA, SIMULIIDAE). *Journal of Medical Entomology,* 28**,** 831-840.

Gagnon, A. S., K. E. Smoyer-Tomic & A. B. G. Bush (2002) The El Nino Southern Oscillation and malaria epidemics in South America. *International Journal of Biometeorology,* 46**,** 81-89.

Gallup, J. L. & J. D. Sachs (2001) The economic burden of malaria. *American Journal of Tropical Medicine and Hygiene,* 64**,** 85-96.

Gao, B. C. (1996) NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment,* 58**,** 257-266.

Githeko, A. K., S. W. Lindsay, U. E. Confalonieri & J. A. Patz (2000) Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization,* 78**,** 1136-1147.

Gleiser, R. M., D. E. Gorla & F. F. L. Almeida (1997) Monitoring the abundance of *Aedes (Ochlerotatus) albifasciatus* (Macquart 1838) (Diptera : Culicidae) to the south of Mar Chiquita Lake, central Argentina, with the aid of remote sensing. *Annals of Tropical Medicine and Parasitology,* 91**,** 917-926.

Goddard, J. (1998) Mosquitoes and yellow fever. *Infections in Medicine,* 15**,** 761-+.

Goodchild, M. F. (1992) GEOGRAPHICAL INFORMATION-SCIENCE. *International Journal of Geographical Information Systems,* 6**,** 31-45.

Graves, P. M., D. E. Osgood, M. C. Thomson, K. Sereke, A. Araia, M. Zerom, P. Ceccato, M. Bell, J. del Corral, S. Ghebreselassie, E. P. Brantly & T. Ghebremeskel (2008) Effectiveness of malaria control during changing climate conditions in Eritrea, 1998-2003. *Tropical Medicine & International Health,* 13**,** 218-228.

Greenwood, B. & T. Mutabingwa (2002) Malaria in 2002. *Nature,* 415**,** 670-672.

Grillet, M. E. & R. Barrera (1997) Spatial and temporal abundance, substrate partitioning and species co-occurrence in a guild of Neotropical blackflies (Diptera: Simuliidae). *Hydrobiologia,* 345**,** 197-208.

Grillet, M. E., M. G. Basanez, S. Vivas-Martinez, N. Villamizar, H. Frontado, J. Cortez, P. Coronel & C. Botto (2001) Human onchocerciasis in the Amazonian area of southern Venezuela: Spatial and temporal variations in biting and parity rates of black fly (Diptera : Simuliidae) vectors. *Journal of Medical Entomology,* 38**,** 520-530.

Han, K. S., A. A. Viau, Y. S. Kim & J. L. Roujean (2005) Statistical estimate of the hourly near-surface air humidity in eastern Canada in merging NOAA/AVHRR and GOES/IMAGER observations. *International Journal of Remote Sensing,* 26**,** 4763-4784.

Harrus, S. & G. Baneth (2005) Drivers for the emergence and re-emergence of vector-borne protozoal and bacterial diseases. *International Journal for Parasitology,* 35**,** 1309-1318.

Hay, S., R. Snow & D. Rogers (1998) Predicting malaria seasons in Kenya using multitemporal meteorological satellite sensor data. *Trans R Soc Trop Med Hyg,* 92**,** 12 - 20.

Heft, D. E. & W. E. Walton (2008) Effects of te El Nino - Southern Oscillation (ENSO) cycle on Mosquito Populations in Southern California. *journal of Vector Ecology,* 33**,** 17-29.

Hendrickx, G., A. Napala, J. H. W. Slingenbergh, R. De Deken & D. J. Rogers (2001) A contribution towards simplifying area-wide tsetse surveys using medium resolution meteorological satellite data. *Bulletin of Entomological Research,* 91**,** 333-346.

Hinzman, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G. L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. M. Welker, K. Winker & K. Yoshikawa (2005) Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climatic Change,* 72**,** 251-298.

Hopp, M. J. & J. A. Foley (2003) Worldwide Fluctuations in Dengue Fever Cases Related to Climate Variability. *Climate Research,* 25**,** 85-94.

Hougard, J. M., L. Yameogo, A. Seketeli, B. Boatin & K. Y. Dadzie (1997) Twenty-two years of blackfly control in the onchocerciasis control programme in West Africa. *Parasitology Today (Personal Ed.),* 13**,** 425-431.

Hudson, P. J., A. P. Dobson & D. Newborn (1998) Prevention of population cycles by parasite removal. *Science,* 282**,** 2256-2258.

Huete, A., K. Didan, T. Miura, E. P. Rodriguez, X. Gao & L. G. Ferreira (2002) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment,* 83**,** 195-213.

Hunter, D. B., C. Rohner & D. C. Currie (1997) Mortality in fledgling great horned owls from black fly hematophaga and leucocytozoonosis. *Journal of Wildlife Diseases,* 33**,** 486-491.

Hurley, A., D. Watts, B. Burke & C. Richards (2004) Identifying gypsy moth defoliation in Ohio using Landsat data. *Environmental & Engineering Geoscience,* 10**,** 321-328.

Kalluri, S., P. Gilruth, D. Rogers & M. Szczur (2007) Surveillance of arthropod vector-borne infectious diseases using remote sensing techniques: A review. *Plos Pathogens,* 3**,** 1361-1371.

Kawamura, K., T. Akiyama, H.-o. Yokota, M. Tsutsumi, T. Yasuda & O. Watanabe (2005) Comparing MODIS Vegetation Indices with AVHRR NDVI for Monitoring the Forage Quantity and Quality in Inner Mongolia Grassland, China. *Grassland Science,* 51**,** 33-40.

Kelly-Hope, L. A., D. M. Purdie & B. H. Kay (2004) Differences in climatic factors between Ross River virus disease outbreak and nonoutbreak years. *Journal of Medical Entomology,* 41**,** 1116-1122.

Khaemba, B., A. Mutani & M. Bett (1994) Studies of anopheline mosquitoes transmitting malaria in a newly developed highland urban area: a case study of Moi University and its environs. *East Afr Med J,* 71**,** 159 - 164.

Killilea, M. E., A. Swei, R. S. Lane, C. J. Briggs & R. S. Ostfeld (2008) Spatial dynamics of Lyme disease: A review. *Ecohealth,* 5**,** 167-195.

Kiszewski, A. E. & E. W. Cupp (1986) Transmission of *Leucocytozoon smithi* (Sporozoa: Leucocytozoidae) by Black Flies (Diptera:Simulidae) in New York, USA. *Journal of Medical Entomology,* 23**,** 256-262.

Kitron, U. (2000) Risk maps: Transmission and burden of vector borne diseases. *Parasitology Today,* 16**,** 324-325.

Koella, J. C., P. Agnew & Y. Michalakis (1998) Coevolutionary interactions between host life histories and parasite life cycles. *Parasitology,* 116**,** S47-S55.

Kulasekera, V. L., L. Kramer, R. S. Nasci, F. Mostashari, B. Cherry, S. C. Trock, C. Glaser & J. R. Miller (2001) West Nile Virus infection in mosquitoes, birds, horses, and humans, Staten Island, New York, 2000. *Emerging Infectious Diseases,* 7**,** 722-725.

Ledrew, E. (1992) REMOTE-SENSING OF ATMOSPHERE-CRYOSPHERE INTERACTIONS IN THE POLAR BASIN. *Canadian Geographer-Geographe Canadien,* 36**,** 336-350.

Lenormand, T., D. Bourguet, T. Guillemaud & M. Raymond (1999) Tracking the evolution of insecticide resistance in the mosquito *Culex pipiens*. *Nature,* 400**,** 861-864.

Li, S. H. & J. L. Brown (1999) Influence of climate on reproductive success in Mexican Jays. *Auk,* 116**,** 924-936.

Lindgren, E., L. Talleklint & T. Polfeldt (2000) Impact of climatic change on the northern latitude limit and population density of the disease-transmitting European tick Ixodes ricinus. *Environmental Health Perspectives,* 108**,** 119-123.

Lindsay, S. W., L. Parson & C. J. Thomas (1998) Mapping the Ranges and Relative Abundance of the Two Principal African Malaria Vectors *Anopheles gambiae sensu stricto* and *An. Arabiensis*, using Climate Data. *Proceedings of the Royal Society B-Biological Sciences,* 263**,** 847-854.

Liu, H. Q. & A. Huete (1995) A FEEDBACK BASED MODIFICATION OF THE NDVI TO MINIMIZE CANOPY BACKGROUND AND ATMOSPHERIC NOISE. *Ieee Transactions on Geoscience and Remote Sensing,* 33**,** 457-465.

Lounaci, A., S. Brosse, A. Thomas & S. Lek (2000) Abundance, diversity and community structure of macroinvertebrates in an Algerian stream: The Sebaou wadi. *Annales de Limnologie,* 36**,** 123-133.

Lysyk, T. J. & T. Danyk (2007) Effect of temperature on life history parameters of adult *Culicoides sonorensis* (Diptera : Ceratopogonidae) in relation to geographic origin and vectorial capacity for bluetongue virus. *Journal of Medical Entomology,* 44**,** 741-751.

Mabaso, M. L. H., I. Kleinschmidt, B. Sharp & T. Smith (2007) El Nino Southern Oscillation (ENSO) and annual malaria incidence in Southern Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* 101**,** 326-330.

Marquardt, W. C. & B. C. Kondratieff. 2005. *Biology of disease vectors*. Burlington, MA: Elsevier Academic Press.

Masek, J. G. (2001) Stability of boreal forest stands during recent climate change: evidence from Landsat satellite imagery. *Journal of Biogeography,* 28**,** 967-976.

McCluskey, B. J., B. J. Beaty & M. D. Salman (2003) Climatic factors and the occurence of vesicular stomatitis in New Mexico, United States of America. *Revue Scientifique Et Technique De L Office International Des Epizooties,* 22**,** 849-856.

McKenzie, V. J. & A. R. Townsend (2007) Parasitic and infectious disease responses to changing global nutrient cycles. *Ecohealth,* 4**,** 384-396.

Mead, D. G., E. W. Gray, R. Noblet, M. D. Murphy, E. W. Howerth & D. E. Stallknecht (2004) Biological transmission of vesicular stomatitis virus (New Jersey serotype) by *Simulium vittatum* (Diptera : Simuliidae) to domestic swine (*Sus scrofa*). *Journal of Medical Entomology,* 41**,** 78-82.

Mead, D. G., C. J. Mare & E. W. Cupp (1997) Vector competence of select black fly species for vesicular stomatitis virus (New Jersey serotype). *American Journal of Tropical Medicine and Hygiene,* 57**,** 42-48.

Meehl, G. A., F. Zwiers, J. Evans, T. Knutson, L. Mearns & P. Whetton (2000) Trends in extreme weather and climate events: Issues related to modeling extremes in projections of future climate change. *Bulletin of the American Meteorological Society,* 81**,** 427-436.

Mellor, P. S., J. Boorman & M. Baylis (2000) Culicoides Biting Midges: Their Role as Arbovirus Vectors. *Annual Review of Entomology,* 45**,** 307.

Metcalf, C. L. (1932) Black Flies and Other Biting Flies of the Adirondacks. *New York State Museum Bulletin***,** 5-58.

Mitchell, J. F. B., J. Lowe, R. A. Wood & M. Vellinga. 2006. Extreme events due to human-induced climate change. 2117-2133. Royal Society.

Montagna, C. M., O. L. Anguiano, L. E. Gauna & A. M. P. de d-Angelo (2003) Mechanisms of resistance to DDT and pyrethroids in Patagonian populations of Simulium blackflies. *Medical and Veterinary Entomology,* 17**,** 95-101.

Mumby, P. J. & A. J. Edwards (2002) Mapping marine environments with IKONOS imagery: enhanced spatial resolution can deliver greater thematic accuracy. *Remote Sensing of Environment,* 82**,** 248-257.

Myint, S. W., M. Yuan, R. S. Cerveny & C. Giri (2008) Categorizing natural disaster damage assessment using satellite-based geospatial techniques. *Natural Hazards and Earth System Sciences,* 8**,** 707-719.

Nair, A., S. Sathyendranath, T. Platt, J. Morales, V. Stuart, M. H. Forget, E. Devred & H. Bouman (2008) Remote sensing of phytoplankton functional types. *Remote Sensing of Environment,* 112**,** 3366-3375.

Narumalani, S., D. R. Mishra & R. G. Rothwell (2004) Change detection and landscape metrics for inferring anthropogenic processes in the greater EFMO area. *Remote Sensing of Environment,* 91**,** 478-489.

Nemani, R. R. & S. W. Running. 1995. Satellite monitoring of global land cover changes and their impact on climate. 395-413. Kluwer Academic Publ.

Ogden, N. H., L. St-Onge, I. K. Barker, S. Brazeau, M. Bigras-Poulin, D. F. Charron, C. M. Francis, A. Heagy, L. R. Lindsay, A. Maarouf, P. Michel, F. Milord, C. J. O'Callaghan, L. Trudel & R. A. Thompson (2008) Risk maps for range expansion of the Lyme disease vector, *Ixodes scapularis*, in Canada now and with climate change. *International Journal of Health Geographics,* 7.

Ortega, M. D., F. R. Holbrook & J. E. Lloyd (1999) Seasonal distribution and relationship to temperature and precipitation of the most abundant species of Culicoides in five provinces of Andalusia, Spain. *Journal of the American Mosquito Control Association,* 15**,** 391-399.

Ostfeld, R. S., C. D. Canham, K. Oggenfuss, R. J. Winchcombe & F. Keesing (2006) Climate, deer, rodents, and acorns as determinants of variation in Lyme-disease risk. *Plos Biology,* 4**,** 1058-1068.

Parmesan, C. (2006) Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology Evolution and Systematics,* 37**,** 637-669.

Pascual, M., X. Rodo, S. P. Ellner, R. Colwell & M. J. Bouma (2000) Cholera dynamics and El Nino-Southern Oscillation. *Science,* 289**,** 1766-1769.

Patz, J. A. & S. H. Olson (2006) Climate change and health: global to local influences on disease risk. *Annals of Tropical Medicine and Parasitology,* 100**,** 535-549.

Perriman, L., D. Houston, H. Steen & E. johannesen (2000) Climate Fluctuation Effects on Breeding of Blue Penguins (*Eudyptula minor*). *New Zealand Journal of Zoology,* 27**,** 261-267.

Pinto, J., C. Bonacic, C. Hamilton-West, J. Romero & J. Lubroth (2008) Climate change and animal diseases in South America. *Revue Scientifique Et Technique-Office International Des Epizooties,* 27**,** 599-613.

Pope, K. O., E. Rejmankova, H. M. Savage, J. I. Arredondojimenez, M. H. Rodriguez & D. R. Roberts (1994) REMOTE-SENSING OF TROPICAL WETLANDS FOR MALARIA CONTROL IN CHIAPAS, MEXICO. *Ecological Applications,* 4**,** 81-90.

Potter, C., P. N. Tan, M. Steinbach, S. Klooster, V. Kumar, R. Myneni & V. Genovese (2003) Major disturbance events in terrestrial ecosystems detected using global satellite data sets. *Global Change Biology,* 9**,** 1005-1021.

Purse, B. V., B. J. J. McCormick, P. S. Mellor, M. Baylis, J. P. T. Boorman, D. Borras, I. Burgu, R. Capela, S. Caracappa, F. Collantes, C. De Liberato, J. A. Delgado, E. Denison, G. Georgiev, M. El Harak, S. De La Rocque, Y. Lhor, J. Lucientes, O. Mangana, M. A. Miranda, N. Nedelchev, K. Nomikou, A. Ozkul, M. Patakakis, I. Pena, P. Scaramozzino, A. Torina & D. J. Rogers (2007) Incriminating bluetongue virus vectors with climate envelope models. *Journal of Applied Ecology,* 44**,** 1231-1242.

Purse, B. V., P. S. Mellor, D. J. Rogers, A. R. Samuel, P. P. C. Mertens & M. Baylis (2005) Climate change and the recent emergence of bluetongue in Europe. *Nature Reviews Microbiology,* 3**,** 171-181.

Purse, B. V., A. J. Tatem, S. Caracappa, D. J. Rogers, P. S. Mellor, M. Baylis & A. Torina (2004) Modelling the distributions of Culicoides bluetongue virus vectors in Sicily in relation to satellite-derived climate variables. *Medical and Veterinary Entomology,* 18**,** 90-101.

Ramsey, E. W., D. K. Chappell & D. G. Baldwin (1997) AVHRR imagery used to identify hurricane damage in a forested wetland of Louisiana. *Photogrammetric Engineering and Remote Sensing,* 63**,** 293-297.

Randolph, S. E. (1998) Ticks are not insects: Consequences of contrasting vector biology for transmission potential. *Parasitology Today,* 14**,** 186-192.

Rawlings, P., R. Capela, M. J. Pro, M. D. Ortega, I. Pena, C. Rubio, A. Gasca & P. S. Mellor. 1998. The relationship between climate and the distribution of *Culicoides imicola* in Iberia. 93-102. Springer-Verlag Wien.

Read, J. M., D. B. Clark, E. M. Venticinque & M. P. Moreira (2003) Application of merged 1-m and 4-m resolution satellite data to research and management in tropical forests. *Journal of Applied Ecology,* 40**,** 592-600.

Reeves, W. C., J. L. Hardy, W. K. Reisen & M. M. Milby (1994) POTENTIAL EFFECT OF GLOBAL WARMING ON MOSQUITO-BORNE ARBOVIRUSES. *Journal of Medical Entomology,* 31**,** 323-332.

Reeves, W. K., P. H. Adler, O. Ratti, B. Malmqvist & D. Strasevicius (2007) Molecular detection of Trypanosoma (Kinetoplastida : Trypanosomatidae) in black flies (Diptera : Simuliidae). *Comparative Parasitology,* 74**,** 171-175.

Reisen, W. K., D. Cayan, M. Tyree, C. A. Barker, B. Eldridge & M. Dettinger (2008) Impact of climate variation on mosquito abundance in California. *Journal of Vector Ecology,* 33**,** 89-98.

Reisig, D. & L. Godfrey (2006) Remote sensing for detection of cotton aphid- (*Homoptera : Aphididae*) and spider mite- (Acari : Tetranychidae) infested cotton in the San Joaquin Valley. *Environmental Entomology,* 35**,** 1635-1646.

Reiter, P. (2001) Climate change and mosquito-borne disease. *Environmental Health Perspectives,* 109**,** 141-161.

Rivers-Moore, N. A., D. A. Hughes & F. C. de Moor (2008) A model to predict outbreak periods of the pest blackfly *Simulium chutteri* Lewis (simuliidae, Diptera) in the Great Fish River, Eastern Cape province, South Africa. *River Research and Applications,* 24**,** 132-147.

Rodgers, S. E., N. J. Miller & T. N. Mather (2007) Seasonal variation in nymphal blacklegged tick abundance in southern new England forests. *Journal of Medical Entomology,* 44**,** 898-900.

Rodgers, S. E., C. P. Zolnik, M. J. Brewer & T. N. Mather (2005) Applications of a climatic water budget to tick-borne disease research. *Physical Geography,* 26**,** 480-488.

Rodgers, S. E., C. P. Zolnik & T. N. Mather (2007) Duration of exposure to suboptimal atmospheric moisture affects nymphal blacklegged tick survival. *Journal of Medical Entomology,* 44**,** 372-375.

Roessig, J. M., C. M. Woodley, J. J. Cech & L. J. Hansen (2004) Effects of global climate change on marine and estuarine fishes and fisheries. *Reviews in Fish Biology and Fisheries,* 14**,** 251-275.

Rogers, D., S. Randolph, R. Snow & S. Hay (2002) Satellite imagery in the study and forecast of malaria. *Nature,* 415**,** 710 - 5.

Romero-Vivas, C. M. E., C. J. Leake & A. K. I. Falconar (1998) Determination of dengue virus serotypes in individual Aedes aegypti mosquitoes in Colombia. *Medical and Veterinary Entomology,* 12**,** 284-288.

Rosenqvist, A., A. Milne, R. Lucas, M. Imhoff & C. Dobson (2003) A review of remote sensing technology in support of the Kyoto Protocol. *Environmental Science & Policy,* 6**,** 441-455.

Roughgarden, J., S. W. Running & P. A. Matson (1991) WHAT DOES REMOTE-SENSING DO FOR ECOLOGY. *Ecology,* 72**,** 1918-1922.

Sallares, R. (2006) Role of environmental changes in the spread of malaria in Europe during the Holocene. *Quaternary International,* 150**,** 21-27.

Salomon, O. D., M. L. Wilson, L. E. Munstermann & B. L. Travi (2004) Spatial and temporal patterns of phlebotomine sand flies (Diptera : Psychodidae) in a cutaneous leishmaniasis focus in Northern Argentina. *Journal of Medical Entomology,* 41**,** 33-39.

Schaeffer, B., B. Mondet & S. Touzeau. 2008a. Using a climate-dependent model to predict mosquito abundance: Application to *Aedes (Stegomyia) africanus* and *Aedes (Diceromyia) furcifer* (Diptera : Culicidae). 422-432.

--- (2008b) Using a climate dependent matrix model to predict mosquito abundance: Application to Aedes(Stegomyia)africanus and Aedes(Diceromyia) furcifer (Diptera : Culicidae), two main vectors of the yellow fever virus in West Africa. *Infection Genetics and Evolution,* 8**,** S45-S45.

Schmidtmann, E. T., W. J. Tabachnick, G. J. Hunt, L. H. Thompson & H. S. Hurd (1999) 1995 epizootic of vesicular stomatitis (New Jersey serotype) in the western United States: An entomologic perspective. *Journal of Medical Entomology,* 36**,** 1-7.

Seelan, S. K., S. Laguette, G. M. Casady & G. A. Seielstad (2003) Remote sensing applications for precision agriculture: A learning community approach. *Remote Sensing of Environment,* 88**,** 157-169.

Sellers, R. F. (1980) Weather, host and vector--their interplay in the spread of insect-borne animal virus diseases. *The Journal Of Hygiene,* 85**,** 65-102.

Sellers, R. F. & A. R. Maarouf (1989) Trajectory analysis and bluetongue virus serotype 2 in Florida 1982. *Canadian Journal Of Veterinary Research = Revue Canadienne De Recherche Veterinaire,* 53**,** 100-102.

--- (1991) POSSIBLE INTRODUCTION OF EPIZOOTIC HEMORRHAGIC-DISEASE OF DEER VIRUS (SEROTYPE-2) AND BLUETONGUE VIRUS (SEROTYPE-11) INTO BRITISH-COLUMBIA IN 1987 AND 1988 BY INFECTED CULICOIDES CARRIED ON THE WIND. *Canadian Journal of Veterinary Research-Revue Canadienne De Recherche Veterinaire,* 55**,** 367-370.

Shanks, G. D., S. I. Hay, D. I. Stern, K. Biomndo & R. W. Snow (2002) Meteorologic Influences on Plasmodium falciparum Malaria in the Highland Tea Estates of Kericho, Western Kenya. *Emerging Infectious Diseases,* 8**,** 1404.

Shelley, A. J. & S. Coscaron (2001) Simuliid blackflies (Diptera: Simuliidae) and ceratopogonid midges (Diptera: Ceratopogonidae) as vectors of *Mansonella ozzardi* (Nematoda: Onchocercidae) in northern Argentina. *Memorias Do Instituto Oswaldo Cruz,* 96**,** 451-458.

Shipp, J. L., B. Grace & H. H. Janzen (1988) INFLUENCE OF TEMPERATURE AND WATER-VAPOR PRESSURE ON THE FLIGHT ACTIVITY OF SIMULIUM-ARCTICUM MALLOCH (DIPTERA, SIMULIIDAE). *International Journal of Biometeorology,* 32**,** 242-246.

Shipp, J. L., B. W. Grace & G. B. Schaalje (1987) EFFECTS OF MICROCLIMATE ON DAILY FLIGHT ACTIVITY OF *SIMULIUM-ARCTICUM MALLOCH* (DIPTERA, SIMULIIDAE). *International Journal of Biometeorology,* 31**,** 9-20.

Silapaswan, C. S., D. L. Verbyla & A. D. McGuire (2001) Land cover change on the Seward Peninsula: The use of remote sensing to evaluate the potential influences of climate warming on historical vegetation dynamics. *Canadian Journal of Remote Sensing,* 27**,** 542-554.

Simas, T., J. P. Nunes & J. G. Ferreira (2001) Effects of global climate change on coastal salt marshes. *Ecological Modelling,* 139**,** 1-15.

Singh, N., S. K. Chand, A. K. Mishra & A. C. Nagpal (2004) Migration malaria associated with forest economy in central India. *Current Science,* 87**,** 1696-1699.

Singh, N. & V. P. Sharma (2002) Patterns of rainfall and malaria in Madhya Pradesh, central India. *Annals of Tropical Medicine and Parasitology,* 96**,** 349-359.

Smith, L. A. & S. J. Thomson (2003) United States Department of Agriculture - Agricultural Research Service research in application technology for pest management. *Pest Management Science,* 59**,** 699-707.

Stockli, R. & P. L. Vidale (2004) European plant phenology and climate as seen in a 20-year AVHRR land-surface parameter dataset. *International Journal of Remote Sensing,* 25**,** 3303-3330.

Stow, D. A., A. Hope, D. McGuire, D. Verbyla, J. Gamon, F. Huemmrich, S. Houston, C. Racine, M. Sturm, K. Tape, L. Hinzman, K. Yoshikawa, C. Tweedie, B. Noyle, C. Silapaswan, D. Douglas, B. Griffith, G. Jia, H. Epstein, D. Walker, S. Daeschner, A. Petersen, L. M. Zhou & R. Myneni (2004) Remote sensing of vegetation and land-cover change in Arctic Tundra Ecosystems. *Remote Sensing of Environment,* 89**,** 281-308.

Subak, S. (2003) Effects of climate on variability in Lyme disease incidence in the northeastern United States. *American Journal of Epidemiology,* 157**,** 531-538.

Tanaka, S. & T. Sugimura (2001) A New Frontier of Remote Sensing from IKONOS Images. *International Journal of Remote Sensing,* 22**,** 1-5.

Thomas, C. D., A. M. A. Franco & J. K. Hill (2006) Range retractions and extinction in the face of climate warming. *Trends in Ecology & Evolution,* 21**,** 415-416.

Valavanis, V. D., G. J. Pierce, A. F. Zuur, A. Palialexis, A. Saveliev, I. Katara & J. J. Wang (2008) Modelling of essential fish habitat based on remote sensing, spatial analysis and GIS. *Hydrobiologia,* 612**,** 5-20.

Valkiūnas, G. 2005. *Avian Malaria Paraistes and Other Haemospordia*. New York: CRC Press.

Vanderberg, J. P. & R. W. Gwadz. 1980. The Transmission by Mosquitoes of Plasmodia in the Laboratory. In *Malaria,* ed. J. P. Kreier, 153-234. New York: Academic Press.

Ward, M. P. (1996) Climatic factors associated with the infection of herds of cattle with bluetongue viruses. *Veterinary Research Communications,* 20**,** 273-283.

Ward, M. P. & S. J. Johnson (1996) Bluetongue virus and the southern oscillation index: Evidence of an association. *Preventive Veterinary Medicine,* 28**,** 57-68.

Wiegand, T., J. Naves, M. F. Garbulsky & N. Fernandez (2008) Animal habitat quality and ecosystem functioning: Exploring seasonal patterns using NDVI. *Ecological Monographs,* 78**,** 87-103.

Wilmers, C. C. & E. Post (2006) Predicting the Influence of Wolf-provided Carrion on Scavenger Community Dynamics under Climate Change Scenarios. *Global Change Biology,* 12**,** 403-409.

Winkler, D. W., P. O. Dunn & C. E. McCulloch (2002) Predicting the effects of climate change on avian life-history traits. *Proceedings of the National Academy of Sciences of the United States of America*, 99**,** 13595-13599.

Yang, X. B. & H. Scherm (1997) El Nino and infectious disease. *Science,* 275**,** 739-739.

Zhou, G., N. Minakawa, A. K. Githeko & G. Y. Yan (2004) Association between climate variability and malaria epidemics in the East African highlands. *Proceedings of the National Academy of Sciences of the United States of America,* 101**,** 2375-2380.

Zhu, C., W. Shi, M. Pesaresi, L. Liu, X. Chen & B. King (2005) The recognition of road network from high-resolution satellite remotely sensed data using image morphological characteristics. *International Journal of Remote Sensing,* 26**,** 5493-5508.

Zomeni, M., J. Tzanopoulos & J. D. Pantis (2008) Historical analysis of landscape change using remote sensing techniques: An explanatory tool for agricultural transformation in Greek rural areas. *Landscape and Urban Planning,* 86**,** 38-46.

Appendix

Table 1. Common arthropod vectors and examples of diseases they transmit. Arthropod groups include insects which include many flies and arachnids, which include deer ticks that commonly carry Lyme disease. There is a range in capability of vectors from a few parasites to many viruses and parasites, as we see in mosquitoes. Information and table is based on Marquart (2005).

Class	**Order(s)**	**Common names**	**Diseases**
Arachnida	Ixodida Trombidiformes Sacroptiformes	Mites, Ticks, & Chiggers	Lyme disease, trombidiosis, cattle tapeworms
Insecta	Hemiptera	Kissing bugs, bed bugs	Chagas disease
	Diptera	Black flies, Mosquitoes, Biting Midges, Tsetse fly	Malaria, River Blindness, vesicular stomatitis virus, Bluetongue Virus, Sleeping sickness
	Phthiraptera	Lice	Salmonella, Typhus, Trench Fever
	Siphonaptera	Fleas	Black Death/plague