Fact Sheet no. 2

Primary Forests and Biodiversity

Forests have high biodiversity compared to other ecosystems

Forest ecosystems are vital refuges for global terrestrial biodiversity. Currently, forests cover less than a third of Earth's land cover, but contain up to 80% of terrestrial biomass and provide habitat for over half of the known terrestrial plant and animal species (Morales-Hidalgo *et. al*. 2015). In 1997, the IUCN estimated that 12.5% of plants, 44% of birds, 57% of amphibians 87% of reptiles and 75% of mammals were threatened by forest decline (Shvidenko 2005).

Species richness is high in tropical forests

Although tropical forests cover less than 10% of the global land area, they harbour up to 90% of Earth's terrestrial species (Shvidenko 2005), largely in the tropical humid forests (Pimm *et al.* 2000). More than half of all known plant species occur in tropical forests. The humid tropical forests of the Amazon, Brazilian Atlantic Forest, Congo, Eastern Arc in Africa and the Southeast Asian mainland and islands house the greatest number of bird and mammal species (Jenkins *et al*. 2013). A single hectare of tropical forest can contain over 300 tree species, even when only stems > 10 cm in diameter are included (Laurance *et al.* 2010).

Tropical regions also have the highest numbers of species in decline (Dirzo *et al*. 2014). Very high rates of predicted extinctions are based on the ongoing loss of tropical forests (Pimm & Raven 2000). These predictions are likely to under-estimate the magnitude of the extinction crisis (Pimm *et al.* 2014), however, as species inventories are very incomplete, especially in poorly studied areas and known biodiversity hotspots (Scheffers *et al.* 2012). It is estimated that as many as half of the plant species and a large number of fauna are yet to be recorded in tropical forests (Laurance 2014). Ongoing deforestation of tropical forests could result in large numbers of species becoming extinct before they are even recorded and described. Because of the way that most species are distributed, the extinction rate is predicted to dramatically increase if we allow the last remnants of habitat to be destroyed (Pimm & Raven 2000). Without urgent action to regenerate forests, many species will continue to decline in forest fragments due to what is known as the extinction debt (Tilman, 1994).

Other biodiversity values are high in boreal and temperate forests

While boreal and temperate forests generally have lower species richness than tropical forests, they support significant numbers of species, many of which are endemic (Wells *et al.* 2013), all of which have unique life histories, and many of which serve vital ecological functions (Bradshaw *et al.* 2009, Robertson *et al.* 2011, Wells & Blancher 2011, Badiou *et al.* 2013, Wells *et al.* 2013). The biodiversity of boreal and temperate forests includes evolutionary lineages uniquely adapted to survive major seasonal temperature changes. These species carry the evolutionary "imprint" of adaptation and resilience to a changing climate (Weckworth *et al.* 2012). Many species of bird, fish and insect that spend part of their lives in temperate and boreal forests have seasonal migrations that take them on vast annual journeys, some of them tens of thousands of kilometres long.

The intact nature of boreal forest ecoregions has fostered geographically widespread and very large populations of some species of plants and animals (Bradshaw *et al.* 2009, Wells et al. 2010, Wells and Blancher 2011, Weckworth et al. 2012, Badiou et al. 2013, Wells et al. 2013). The boreal forest ecoregion is one of few left on Earth where large-scale migrations of land mammals continue largely unimpeded as migratory tundra caribou herds move thousands of kilometres between calving and wintering grounds (Hummel & Ray 2008, Badiou *et al*. 2011).

Maintaining the biodiversity of primary forests is crucial for Earth's ecological integrity

Forests do not exist in isolation but are integral to Earth's ecological integrity. In particular, the remaining primary forests including their biota have a vital role in global climate regulation and hydrological processes (Badiou *et al.* 2013). The boreal forest, for example, contains the largest terrestrial below-ground stores of carbon (Bradshaw et al. 2009, Carlson et al. 2009, 2010, 2015) while tropical and temperate forests are the largest terrestrial stores of above-ground carbon. In addition, the physiological processes of large intact primary forests impact weather and climate on shorter time scales as they alter the global atmospheric distribution of carbon dioxide, and impact precipitation, temperature and wind at continental scales. Unregulated rivers that flow from large, intact primary forest areas, and the nutrients that they carry, are a major determinant of biological productivity in estuaries and oceans worldwide. The water flow from major rivers including the cold, dense water that flows from boreal forest rivers, establishes global ocean currents that drive global weather patterns as well as global marine biodiversity patterns (Schindler & Lee 2010, Wells *et al.* 2011).

The boreal forest is vital for maintaining populations of migratory species that are integral to ecosystems around the world. For example, the North American Boreal functions as a nursery for 325 migratory bird species. Up to 3 billion birds breed there during the boreal summer and up to five billion birds migrate southwards to become common species in temperate and tropical ecosystems throughout North, Central and South America for the boreal winter (Robertson *et al.* 2011, Wells & Blancher 2011). Here these species fulfil important ecological roles as pollinators, seed dispersers, nutrient processors, predators, prey and scavengers (Wells *et al.* 2014). Similarly spectacular latitudinal migrations occur on other continents, although many are being imperilled by the loss of key stopover habitats that are vital for energy-stressed migrating birds.

Primary forests are irreplaceable for biodiversity

Many studies have found that a high proportion of forest species, including plants and animals, are sensitive to disturbance and only occur in primary forest (Hermy & Verheyen 2007, Morales-Hidalgo *et al.* 2015). Barlow et al. (2007) found that almost 60% of tree and vine genera and 40% of birds in the Brazilian Amazon were only ever recorded in primary forest. Obligate forest species are intrinsically more vulnerable to extinction from deforestation and forest degradation and are often of the highest priority for conservation (Laurance *et al.* 2002).

Species respond in different ways to deforestation and degradation (Barlow *et al.* 2007, Gardner *et al.* 2009, Moura *et al.* 2015). Generally, however, forest biodiversity declines with increasing land-use intensity (Zapfack *et al.* 2002, Philpott *et al.* 2008, Gibson *et al.* 2011, Burivalova *et al.* 2014, de Castro Solar *et al.* 2015, Newbold *et al.* 2015). Increasing levels of disturbance lead to biotic homogenization as disturbance-sensitive species are lost and replaced by generalist species with high dispersal abilities (Bawa & Seidler 1997, de Castro Solar *et al.* 2015). Young forests are mainly occupied by widespread species that occur in a range of vegetation types (Liebsch *et al.* 2008).

Faunal communities change in response to physical changes in habitat. This can be observed as a spatial tapestry of ecosystems across landscapes. Changes in faunal communities can also be observed through time as vegetation matures. Even species that might be expected to be mobile, such as birds, can be exclusively associated with old growth forest (Loyn 1985, Venier & Pearce, 2005, Sallabanks *et al*. 2006, Gould & Mackey 2015). In the temperate eucalypt forests of Australia, for example, the density of big old trees is specifically associated with the abundance of a number of vertebrates that are dependent on tree hollows for breeding (McElhinny *et al.* 2006).

Large intact areas are required to protect viable populations

The spatial pattern of biodiversity distribution is generated by ecological processes including species' life histories. Protecting biodiversity requires that we account for the spatial and temporal scale of those processes. The large scale of ecological processes in the boreal forest means that large intact landscapes are required to protect biodiversity (Badiou *et al.* 2013). Intact boreal forest provides refuge for viable populations of species that require large home ranges. The woodland caribou, for example, is recognised as an indicator of boreal forest intactness that has disappeared from half of its historic range, primarily as a result of habitat loss. The woodland caribou requires large areas of intact forest for the slow-growing lichens that sustain them through winter (Badiou *et al.* 2011). The International Boreal Conservation Science Panel has recommended that reserves in North America's Boreal Forest region should be at least one to two million hectares in area to protect woodland caribou and other species and to maintain ecological functionality (Badiou *et al.* 2013).

Tropical forests also need large continuous areas of ecologically intact forest if they are to sustain a full complement of species and landscape scape ecological processes over evolutionary time frames (Peres 2005, Gibson *et al.* 2013, Hanski *et al.* 2013). Peres (2005), for example, estimates that protecting tropical biodiversity in the Brazilian Amazon will require reserves larger than one million hectares to maintain genetically viable populations of large, rare carnivores which can have an important role in structuring ecological communities (Terborgh *et al.* 2001).

Large reserves are also required to account for the high proportion of unknown species, allow for the recovery of harvest sensitive species that are traditionally harvested, and to preserve the full

complement of habitats required for long term survival of seasonally migratory species. Large reserves are more likely to be resilient to climate change, to deforestation induced changes in rainfall, and to dessication and fire that follow deforestation and forest degradation. Large reserves are also likely to be more able to support populations through events such as periodic droughts (Laurance 2004).

In tropical forests, the spatial and temporal scales of disturbance are important aspects of natural regeneration. Some individual trees are very slow growing, have very long life spans, and are adapted to shade tolerance and small-scale canopy-gap dynamics (Zimmerman & Kormos, 2012). Their high tree diversity also depends on the presence of specialised animal vectors for pollination and seed dispersal. Although individual tree species typically occur at low densities (Pitman *et al.* 1999), they are able to sustain sparse regeneration at the stand scale under the right conditions including an intact canopy, residual seed trees and key fauna. Consequently, biodiversity in tropical forest ecosystems is highly sensitive to logging and other disturbances, such as overhunting.

Selectively logged forests are also critical for conserving tropical nature

Selective logging has significant direct effects on forest structure. For example, removal of as few as 3% of the trees can reduce canopy cover by as much as 50% (Bawa & Seidler 1997). Opening up of the canopy changes light and temperature conditions, dries the soil, creates large amounts of flammable slash and thereby increases the risk of fire, changes the distribution of forest resources for fauna, and alters species interactions. In addition to the direct effects on forest structure, disturbance can cause significant change in the composition and richness of plants and animals (Schulze et al. 2004, Liebsch *et al.* 2008).

Nevertheless, compared with more intensive land uses such as agriculture and agroforesty, selectively logged forests can retain much of their plant and animal diversity and substantial carbon stores and hydrological functions. Selective logging generally targets a few species of commercial importance leaving other species unharvested (Laurance & Edwards 2014). Selectively logged forests (largely after a single cutting cycle) can retain a high richness of forest species (Gibson *et al.* 2011) although different taxonomic groups vary in their responses to logging intensity (Burivalova *et al.* 2014). Protecting and restoring selectively logged forests could help to increase the area of the conservation state in many tropical nations.

Protecting primary forests and restoring selectively logged forests is critical for averting further biodiversity losses

The Earth's sixth mass extinction event is already well underway. Up to 33% of all vertebrate species and 40% of invertebrates are estimated to be globally threatened or endangered, and there has been an average 28% decline in the abundance across all vertebrate species over the last four decades (Dirzo *et al.* 2014). Before species become globally extinct, local populations are extirpated across wide areas, with significant losses of individuals. Whereas global extinction may take a long time, local population declines to levels at which species are functionally extinct can occur quickly and with immediate impacts on ecosystem function. In turn, this process of 'defaunation' becomes a driver of global environmental change with profound ecological consequences (Dirzo et al. 2014).

Currently, only 13% of the world's forests are primarily designated for conservation. Averting further loss of biodiversity and the consequent loss of ecosystem services are still possible through intensified conservation efforts – but the window of opportunity is closing rapidly (Ceballos *et al.* 2015). To minimize extinctions, rapid action is required to conserve the remaining primary forests and restore function to degraded and fragmented forest landscapes (Gibson *et al.* 2013).

Forests can regenerate but the direction and speed of regeneration depends on the type and persistence of land-use legacies (Cramer 2008). Recovery of species composition similar to the original primary forest may require hundreds of years to millennia (Foster *et al.* 2003, Dambrine *et al.* 2007, Liebsch *et al*. 2008, Gardner *et al.* 2009) and is not guaranteed (Cramer 2008). Protecting the remaining primary forests is therefore the highest priority action for sustaining biodiversity (Faria *et al.* 2007, Gibson *et al.* 2011, de Castro Solar *et al.* 2015). A second priority is ensuring that selectively logged forests in the tropics, which comprise some 400 million hectares worldwide, are protected to the greatest extent possible. Many of the logged forests are being rapidly cleared for industrial and small-scale farming and other land uses (Laurance and Edwards 2014).

References

Badiou, P., Boutin, S., Carlson, M., Darveau, M., Drapeau, P., Jacobs, J., Johnson, C., Kerr, J., Manseau, M., McLoughlin, P., Orians, G., Pimm, S., Raven, P., Roberts, D., Root, T., Roulet, N., Schaefer, J., Schindler, D., St-Laurent, M., Stritthol, J., Turner, N., Weaver, A. and Wells, J. (2011) Keeping woodland caribou in the boreal forest: Big challenge, immense opportunity. International Boreal Conservation Science Panel.

Badiou, P., Baldwin, R., Carlson, M., Darvearu, M., Drapeau, P., Gaston, K., Jacobs, J., Kerr, J., Levin, S., Manseau, M., Orians, G., Pimm, S., Possingham, H., Paven, P., Reid, F., Roberts, D., Root, T., Roulet, N., Schaefer, J., Schindler, D., Strittholt, J., Turner, N. and Wells, J. (2013) Conserving the World's Last Great Forest Is Possible: Here's How. International Boreal Conservation Science Panel.

Barlow, J., Gardner, T.A., Araujo, I.S., Ávila-Pires, T.C., Bonaldo, A.B., Costa, J.E., Esposito, M.C., Ferreira, L.V., Hawes, J., Hernandez, M.I.M., Hoogmoed, M.S., Leite, R.N., Lo-Man-Hung, N.F., Malcolm, J.R., Martins, M.B., Mestre, L.A.M., Miranda-Santos, R., Nunes-Gutjahr, A.L., Overal, W.L., Parry, L., Peters, S.L., Ribeiro-Junior, M.A., da Silva, M.N.F., da Silva Motta, C. and Peres, C.A. (2007) Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. *Proceedings of the National Academy of Sciences*, **104:** 18555-18560.

Bawa, K. and Seidler, R. (1997) Natural forest management and conservation biodiversity in tropical forests. *Conservation Biology,* **12:** 46-55.

Bradshaw, C. J. A., Warkentin, I.G. and Sodhi, N.S. (2009) Urgent preservation of boreal carbon stocks and biodiversity. *Trends in Ecology and Evolution,* **24**: 541–548.

Burivalova, Z., Şekercioğlu, C.H. and Koh, L.P. (2014) Thresholds of logging intensity to maintain tropical forest biodiversity. *Current Biology*, **24**: 1893-1898.

Ceballos, G. Ehrlich, P.R., Barnosky, A.D., García, A., Pringle, R.M. and Palmer, T.M. (2015) Accelerated modern human-induced species losses: Entering the sixth mass extinction. *Science Advances*, 1:e1400253.

Carlson, M., J. Wells and Roberts, D. (2009) The carbon the world forgot: Conserving the capacity of Canada's boreal forest region to mitigate and adapt to climate change. Boreal Songbird Initiative and Canadian Boreal Initiative, Seattle and Ottawa, Ontario. 33 pp.

Carlson, M., et al. 2010. Maintaining the role of Canada's forests and peatlands in climate regulation. *Forestry Chronicle*, **86**: 1-10.

Carlson M., Wells J. and Jacobson, M. (2015) Balancing the relationship between protection and sustainable management in Canada's boreal forest. *Conservation and Society*, **13:** 13–22.

Cramer, V.A., Hobbs, R.J., and Standish, R.J., (2008) What's new about old fields? Land abandonment and ecosystem assembly. Trends in Ecology and Evolution, **23:** 104-112.

de Castro Solar, R.R., Barlow, J., Ferreira, J., Berenguer, E., Lees, A.C., Thomson, J.R., Louzada, J., Maués, M., Moura, N.G., Oliveira, V.H.F., Chaul, J.C.M., Schoereder, J.H., Guimarães Vieira, I.C., Mac Nally, R. and Gardner, T.A. (2015) How pervasive is biotic homogenization in human-modified tropical forest landscapes? *Ecology Letters*, **18:**1108-1118.

Dambrine, E., Dupouey, J.-L. Laut, L., Humbert, L., Thinon, M., Beaufils, T. and Richar, H. (2007) Present forest biodiversity patterns in France related to former Roman agriculture. *Ecology*, **88:**1430-1439.

Dirzo, R., Young, H.S., Galetti, M., Caballos, G., Isaac, N.J.B. and Collen, B. (2014) Defaunation in the Anthropocene. *Science*, **345:** 401-406.

Faria, D., Paciencia, M.L.B., Dixo, M., Laps, R.R. and Baumgarten, J. (2007) Ferns, frogs, lizards, birds and bats in forest fragments and shade cacao plantations in two contrasting landscapes in the Atlantic forest, Brazil. *Biodiversity Conservation*, **16**: 2335-2357.

Foster, D., Swanson, F., Aber, J., Burke, I., Brokaw, N., Tilman, D. and Knapp, A. (2003) The importance of land-use legacies to ecology and conservation. *BioScience*, **53:** 77-88.

Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A. and Sodhi, N.S. (2009) Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters*, **12:** 561-582.

Gibson, L., Lee, T.M., Koh, L.P., Brook, B.W., Gardner, T.A., Barlow, J., Peres, C.A., Bradshaw, C.J., Laurance, W.F., Lovejoy, T.E. and Sodhi, N.S. (2011) Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature*, **478:** 378-381.

Gibson, L., Lynam, A.J., Bradshaw, C.J.A., He, F., Bickford, D.P., Woodruff, D.S., Bumrungsri, S. and Laurance, W.F. (2013) Near-complete extinction of native small mammal fauna 25 years after forest fragmentation. *Science*, **341**: 1508-1510.

Gould, S.F. and Mackey, B.G. (2015) Site vegetation characteristics are more important than landscape context in determining bird assemblages in revegetation. *Restoration Ecology*, 23: 670-680.

Hanski, I., Zurita, G., Bellocq, M.I. and Rybicki, J. (2013) Species-fragmented area relationship. *Proceedings of the National Academy of Sciences:* **110:** 12715-12720.

Hermy, M. and Verheyen, K. (2007) Legacies of the past in the present-day forest biodiversity: a review of past land-use effects on forest plant species composition and diversity. *Ecological Restoration*, **22:** 361-371.

Hummel, M., and Ray, J.C. (2008) *Caribou and the north: a shared future*. Dundurn Press, Toronto.

Jenkins, C.N., Pimm, S.L. and Joppa, L.N. (2013) Global patterns of terrestrial vertebrate diversity and conservation. *Proceedings of the National Academy of Sciences*, **110:** E2602-E2610.

Laurance, S.G.W., Andrade, A. and Laurance, W.F. (2010) Unanticipated effects of stand dynamism of Amazonian tree diversity. *Biotropica*, **42**: 429-434.

Laurance, W.F. (2004) When bigger is better: the need for Amazonian mega-reserves. *Trends in Ecology and Evolution*, **20:** 645-648.

Laurance, W.F. and Edwards, D. (2014) Saving logged tropical forests. *Frontiers in Ecology and Evolution*, **12**:147.

Laurance, W. F., Lovejoy, T.E., Vasconcelos, H.L., Bruna, E,M., Didham, R.K., Stouffer, P.C., Gascon, C., R. O. Bierregaard, R.O., Laurance, S.G. and Sampiao, E. 2002. Ecosystem decay of Amazonian forest fragments: a 22-year investigation. *Conservation Biology,* **16**:605-618.

Liebsch, D. Marques, M.C.M. and Goldenberg, R. (2008) How long does the Atlantic Rain Forest take to recover after a disturbance? Changes in species composition and ecological features during secondary succession. *Biological Conservation*, **141:** 1717-1725.

Loyn, R.H. (1985) Bird populations in successional forests of mountain ash, *Eucalyptus regnans*, in central Victoria. *Emu*, **85:** 213-231.

McElhinny, C., Gibbons, P., Brack, C. and Bauhaus, J. (2006) Fauna-habitat relationships: a basis for identifying key stand structural attributes in temperate Australian eucalypt forests and woodlands. *Pacific Conservation Biology*, **12**: 68-110.

Morales-Hidalgo, D., Oswalt, S.N. and Somanthan, E. (2015) Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015*. Forest Ecology and Management*, **352:** 68-77.

Moura, N., Lees, A.C., Aleixo, A., Barlow, J., Berenguer, E., Ferreira, J., Mac Nally, R., Thomson, J.R. and Gardner, T.A. (2016) Idiosyncratic responses of Amazonian birds to primary forest disturbance. *Oecologia*, **180:** 903-916.

Newbold, T., Hudson, L.N., Hill, S.L.L., Contu, S., Lysenko, I., Senior, R.A., Borger, L., Bennett, D.J., Choimes, A., Collen, B., Day, J., De Palma, A., Diaz, S., Echeverria-Londono, S., Edgar, M., Feldman, A., Garon. M., Harrison, M.L.K., Alhusseini, T., Ingram, D.J., Itescu, Y., Kattge, J., Kemp. V., Kirkpatrick, L., Kleyer, M., Correia, D.L.P., Martin, C.D., Meiri, S., Novosolov, M., Pan, Y., Phillips, H.R.P., Purves, D.W., Robinson, A., Simpson, J., Tuck, S.L., Weiher, E., White, H.J., Ewers, R.M., Mace, G.M., Scharlemann, J.P.W. and Purvis, A. (2015) Global effects of land use on local terrestrial biodiversity. *Nature*, **520:** 45-50.

Peres, C.A. (2005) Why we need megareserves in Amazonia. *Conservation Biology*, **19:** 728-733.

Philpott, S.M., Arendt, W.J., Armbrecht, I., Bichier, P., Dietsch, T.V., Gordon, C., Greenberg, R., Perfecto, I., Reynoso-Santos, R., Soto-Pinto, L., Tejeda-Cruz, C., Williams-Linera, G., Valenzuela, J. and Zolotoff, J.M. (20008) Biodiversity loss in Latin America coffee landscapes: review of the evidence on ants, birds and trees. *Conservation Biology*, **22:** 1093-1105.

Pimm, S.L., Jenkins, C.N., Bell, R., Brooks, T.M., Gittleman, J.L., Joppa, L.N., Raven, P.H., Roberts, C.M. and Sexton, J.O. (2014) The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, **344**: 987-998.

Pimm, S.L. and Raven, P. (2000) Extinction by numbers. *Nature*, **403**:843-845.

Pitman, N.C.A., Terborgh, J., Silman, M.R. and Nuñez, V. (1999) Tree species distribution in an upper Amazonian forest. Ecology, **80:** 2651-2661.

Robertson, B.A., MacDonald, R., Wells, J.V., Blancher, P. and Bevier, L. (2011) Chapter 7: Boreal migrants in winter bird communities. Pp. 85–94 in (J.V. Wells, ed.) Boreal birds of North America. Studies in Avian Biology (no. 41), University of California Press: Berkeley, California.

Sallabanks, R., Haufler, J.B. and Mehl, C.A. (2006) Influence of forest vegetation structure on avian community composition in west-central Idaho, *Wildlife Society Bulletin*, **43:** 1079-1093.

Scheffers, B.R., Joppa, L.N., Pimm, S.L. and Laurance, W.F. (2012) What we know and don't know about Earth's missing biodiversity. *Trends in Ecology and Evolution*, **27**: 501-510.

Schindler D. and Lee P. (2010) Comprehensive conservation planning to protect biodiversity and ecosystem services in Canadian boreal regions under a warming climate and increasing exploitation. *Biological Conservation*, **143:** 1571–1586.

Schulze, C.H., Walter, M., Kessler, P.J.A., Pitopang, R., Shahabuddin, Veddeler, D., Muhlenberg, M., Gradstein, R., Leuschner, C., Steffan-Dewenter, I. and Tscharntke, T. (2004) Biodiversity indicator groups of tropical land-use systems: comparing plants, birds and insects. *Ecological Applications*,**14:** 1321-1333.

Shvidenko, A., Barber, C.V., Persson, R. (Editors)(2005) Forest and Woodland Systems. Chapter 21, *Millennium Ecosystem Assessment*. World Resources Institute, Washington, DC.

Terborgh, J., Lopez, L., Nunez, P.V., Rao, M., Shahabuddin, G., Orihuela, G., Riveros, M., Asciano, R., Adler, G.H., Lambert, T.D. and Balbas, L. (2001) Ecological meltdown in predator-free forest fragments. *Science*, **294**: 1923-1926.

Tilman, D., May, R.M., Lahman, C.L. and Nowak, M.A. (1994) Habitat destruction and the extinction debt. *Nature*, **371:** 65-66.

Venier, L.A. and Pearce, J.L. (2005) Boreal bird community response to jack pine forest succession. *Forest Ecology and Management*, **217:** 19-36.

Weckworth, B.V., Musiani, M., McDevitt, A.D., Hebblewhite, M. and Mariani, S. 2012. Reconstruction of caribou evolutionary history in Western North America and its implications for conservation. *Molecular Ecology*, **21**: 3610-3624.

Wells, J. and Blancher, P. (2011) Global role for sustaining bird populations. In: *Boreal birds of North America: a hemispheric view of their conservation links and significance* (ed. J. Wells). University of California Press, Berkeley.

Wells, J.V., Roberts, D., Lee, P., Cheng, R. and Darveau, M. (2011) A forest of blue: Canada's Boreal Forest, the world's waterkeeper. Pew Environment Group, Washington.

Wells, J., Reid, F., Darveau, M. and Childs, D. (2013) Ten Cool Canadian Biodiversity Hotspots: How a New Understanding of Biodiversity Underscores the Global Significance of Canada's Boreal Forest. Boreal Songbird Initiative, Seattle, Washington, Ducks Unlimited Inc., Memphis, Tennessee, and Ducks Unlimited Canada, Stonewall, Manitoba.

Wells, J., Childs, J., Reid, F., Smith, K., Darveau, M. and Courtois, V. (2014) Boreal Birds Need Half: Maintaining North America's Bird Nursery and Why it Matters. Boreal Songbird Initiative, Seattle, Washington, Ducks Unlimited Inc., Memphis, Tennessee, and Ducks Unlimited Canada, Stonewall, Manitoba.

Zapfack, L., Engwald, S., Sonke, B., Achoundong, G. and Madong, B. (2002) The impact of land conversion on plant biodiversity in the forest zone of Cameroon. *Biodiversity and Conservation*, **11:** 20147-2061.

Zimmerman, B.L. and Kormos, C.F. (2012) Prospects for sustainable logging in tropical forests. *BioScience*, **62:** 479-487.