HETERODOX ECONOMICS AND THE BIODIVERSITY CRISIS

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Economists must engage with environmental issues such as the biodiversity crisis and heterodox economics provides a more fruitful set of tools than the orthodox approach for doing so. Biodiversity refers to the variability of living organisms at the genetic, species and ecosystem levels and the ecological complexes or interdependencies between species (MEA 2005; DEST 1996: 1; OTA 1987: 3). Through our economic activity, humans have reduced biodiversity to the point where it can be classified as being at crisis-point. For example, there have been 100 well documented extinctions of birds, mammals and amphibians over the last 100 years; and the extinction rate is 100 to 1,000 times the extinction rate experienced without human influence (MEA 2005: 3-4). In Australia, a biodiversity hotspot, 27 of approximately 350 native mammals have become extinct since European settlement (Department of the Environment, n.d.). Across all taxonomic groups there has been a decline in population sizes and/or ranges for the majority of species (MEA 2005: 3) and 10-50% of mammals, birds, amphibians, conifers and cycads are threatened with extinction (MEA 2005: 4). Genetic, species and ecosystem diversity has declined substantially at a global level and species interdependencies have been compromised.

These losses impact directly and indirectly on human wellbeing. Directly, biodiversity contributes provisioning, regulating and cultural ecosystem services (MEA 2005: 5). Provisioning services refer to the food, raw materials, and medicines provided by *in situ* species. Regulating services refer to pollination activities and biological controls needed for modern agriculture, along with the carbon sequestration and storage needed for human existence. That is, as part of the carbon cycle, plants convert unbreathable carbon dioxide into oxygen and a significant reduction in the number and abundance of plants would make life on Earth untenable.

Cultural services refer to aesthetic appreciation and inspiration for art and recreation. Indirectly, by increasing the resilience of ecosystems, biodiversity underpins ecosystem services (MEA 2005: 5), such as local climate and air quality regulation, waste-water treatment, prevention of erosion and the maintenance of soil fertility, as well as the production of new medicines and agricultural products (TEEB, n.d.).

The identification of the biodiversity-loss problem as a 'crisis' derives from the recognition of threshold effects or tipping points. For example, Ehrlich and Ehrlich (1981), in their rivet popper metaphor, liken ecosystems to an airplane held together by thousands of rivets (species). If just one rivet is popped (one species becomes extinct), the plane is weakened but it will probably not fall apart. However, after many rivets are popped a tipping point is reached and one more popped rivet leads to the destruction of the plane. This metaphor highlights the fact that biodiversity is subject to sudden, non-linear changes or abrupt regime shifts that result from a gradual weakening of the system (MEA 2005: 6). Thus, there is a biodiversity 'crisis' because biodiversity is exceedingly valuable to humans, extinctions and population reductions continue at an alarming rate, and a threshold effect could result in mass extinctions.

Far from being a neutral input that guides ecological policymaking, economic understandings of biodiversity influence policymaking in ways that may be counterproductive to the kinds of holistic decision-making processes needed for effective conservation practices (Robertson and Hull 2001). It is, therefore, critical to scrutinise the manner in which biodiversity is represented in prevailing economic epistemologies, as this affects not only the way biodiversity is perceived and understood, but also how it is implemented in policy, management and conservation practices.

Many of the policy tools used to manage the biodiversity crisis derive from orthodox economics. Orthodox economists describe the loss of biodiversity as a 'market failure' or, equivalently, as a free-rider or open-access resource problem, an externality, or the result of missing property rights (Helm and Hepburn 2012; Folk 2006; Kahn 1995). Thus, the solutions put forward by orthodox economists resemble the solutions to any market failure. In particular, the solution is to 'get the prices right' or internalise the externality. Atomistic and rational agents are simply responding to the wrong incentives. While policy traditionally followed a direct regulation approach, as with endangered species legislation and the establishment of protected areas, emphasis has shifted to incentive-based policies. These may involve taxing activities that cause biodiversity loss, such as fertilizers, pesticides, land conversion and air pollution, or providing subsidies for activities that conserve biodiversity, such as setting aside land in conservation easements (Helm and Hepburn 2012: 11-3). More recently, market-based solutions have been devised to offset the effect of economic activity on wetlands, streams, species and ecosystems. As of 2010, there were 39 market-based schemes and another 25 being developed around the world, with an annual global market size of USD 1.8 – 2.9 billion (Madsen *et al.* 2010: iv). Australia has eleven active programs, including the NSW government's Biobanking scheme which allows developers to reduce biodiversity in one area by purchasing biodiversity credits on an open market (OEH 2012).

Although these policy approaches have a firm theoretical foundation and may be useful in some circumstances, they are blunt instruments. Like removing unemployment benefits to encourage the unemployed to work, they do not get to the root cause of the problem, which is a shortage of vacancies and opportunities. In contrast to prevailing narratives of biodiversity, in which the foundations of neoclassical economics are taken as given, we argue that, due to its ethical and ontological foundations, orthodox economics is incapable of solving the biodiversity loss problem and that heterodox economics provides a more useful method of analysis.

The Ethical and Ontological Foundations of Orthodox Economics Undermine Endangered Species Management

Orthodox economic theory is founded upon a specific ethic – utilitarian consequentialism. Consequentialism is the belief that the only relevant aspects of a decision are its consequences (Wilber 1999: 286). Orthodox economics (McCain 1991) and, in particular, welfare economics (Roth 1999: 96) – and hence orthodox environmental economics (Bromley 2004: 73) – is specifically concerned with the utility or welfare consequences. Cost-benefit analysis typifies the practical application of a consequentialist ethic where everything becomes commensurate and expressible in terms of a common monetary metric. Thus, the consequentialist approach leads to value-monism; and many types of different values, such as those associated with development and conservation, become substitutable.

The orthodox model also assumes a specific social and, we argue, natural ontology. Ontology is the philosophical inquiry into the nature and basic structure of phenomena of a domain of reality (Lawson 2003: 12). Orthodox theory assumes an atomistic ontology which critical realists and heterodox economists argue is ill-suited to studying the socio-economic world (Lewis 2004:1). In particular, the theory affords importance to event regularities of the kind: 'whenever event or state of affairs *x*, then event or state of affairs *y*' (Lewis 2004: 3). This is often evident in the mathematical formalism of the orthodox approach. Instead, critical realists and heterodox economists argue that open systems prevail, in which event regularities are largely absent (Lewis 2004: 3). In open systems, fundamental uncertainty and complexity reign supreme, and this is as evident in the natural world as it is in the social world.

Due to these ethical and ontological foundations, orthodox economic models of endangered species management, and the policies that derive from them, will undermine the very values that the models purport to foster. To illustrate, we discuss two well-cited papers in the orthodox economics literature on biodiversity conservation.

General Equilibrium and Economic Harvests

The first model, described in Finnoff and Tschirhart (2003a), appeared in the orthodox economic journal *Land Economics* and has since been widely cited and extended (Finnoff and Tschirhart 2003b, 2008; Tilman *et al.* 2005; Finnoff *et al.* 2005). The authors apply general equilibrium theory to an ecosystem. Individual plants and animals behave rationally and maximise their welfare, measured by their net energy intake. Net energy is the driver of reproduction and, according to the authors, 'natural selection requires plants and animal to use energy efficiently' (Finnoff and Tschirhart 2003a: 165). Net energy determines population growth, just as profits determine industry growth in a perfectly competitive economy. In fact, each species in the ecosystem is modelled as an industry, each individual member of each species represents a firm, and the individuals exchange energy with other species instead of goods and services.

For example, the model is applied to a real (but simplified) marine ecosystem off Alaska and the following exchanges occur. The killer whale consumes the Steller sea lion and receives energy. The sea lion consumes pollock which feeds on various species of zooplankton which consume phytoplankton which 'prey' on the sun for energy (Finnoff and Tschirhart 2003a: 167). The killer whale can also partake in another food chain where it eats the sea otter which consumes sea urchin which feeds on kelp which also 'preys on' the sun. Each prey species in the food chain gives up energy to predators when eaten and each predator uses up energy in searching for and killing the prey. The individuals of each species make decisions by calculating the marginal benefit and price of a catch. The marginal benefit is the energy received from a catch. The price is an 'energy price' (one for each species) which is the energy required to pursue and catch a representative individual of the species (Finnoff and Tschirhart 2003a: 166). The more abundant a prey species is, the lower its price and the more it gets preyed upon.

This model is used to describe optimal harvest levels of the pollock, which is preyed upon by the endangered Steller sea lion. Society cares about the harvest because people like eating fish but people also care about the endangered species, perhaps due to its existence, scientific or recreation value, moral imperatives, or the need to maintain an ecologically important species (Finnoff and Tschirhart 2003a: 163). Simulations are run and the model illustrates the impact on the endangered species population and economic welfare when the pollock harvest changes. The population adjustments are analogous to the adjustment of firms in a long-run competitive equilibrium model. Thus, the short-run equilibrium is a stable position where each individual is maximizing their net energies, but these net energies (profits) can be positive or negative. The long-run equilibrium is where all net energies are zero – each individual gets as much as it gives off – and the population size of each species is therefore stable. For example, if the harvest level of pollock increases, this reduces the abundance and increases the energy price of the pollock because the sea lion spends more time finding and consuming them. The sea lion may rationally choose to substitute for another input if available, which is not modelled, or each individual may rationally choose not to find pollock because the energy price is too high. That is, the amount of energy expended in seeking out the pollock is less than the energy provided from consuming it. In this way, the individual may rationally choose to die. Of course, like the exiting of a firm in an industry, if one individual dies, this makes it easier for the rest of the species to catch the pollock and a new long-run equilibrium is formed with a lower population of the endangered species.

With the best of intentions, the authors are attempting a monumental task. Their model incorporates multiple ecological-based equations describing the population growth rates of each species in terms of energy prices, equations describing the behaviour of individuals and the way each species interacts with others, and the economic (demand for harvest) side of the model. At first glance they appear to avoid the direct trade-offs between economic and ecological values that typifies the orthodox economic approach. The typical economic approach to the problem, which the authors concede is one possible path (Finnoff and Tschirhart 2003a: 163), would be to include the value of the endangered species in the economic objective function along with the harvest value of the fish. Thus, the harvest would be directly tradeable with the value of the endangered species, and the endangered species could be harvested to extinction if the fish-harvest was valued highly enough. This reflects the value-monism underlying orthodox economics which, as mentioned, allows substitution between different values. The authors appear to avoid this value-monism by including a constraint in the optimisation model that requires the endangered species to recover to its minimum viable population (MVP) (Finnoff and Tschirhart, 2003a: 164). No attempt is made to value the endangered species in monetary terms and include this in the objective function. Instead, to find the optimal harvest (in theoretical terms), shadow prices for the MVP constraint effectively monetise the growth in the sea lion stock. That is, the value of the MVP program is the opportunity cost – the harvest value forgone.

The use of the MVP constraint might be described as a kind of duty-based or deontological ethic rather than utilitarian consequentialism.[1] Indeed, Finnoff and Tschirhart (2003a: 163) stress moral concerns when discussing reasons for saving the endangered species. However, despite the emphasis on moral duties, there is still a consequentialist ethic at the core of the model, as there must be in orthodox economics. The authors

1 A deontological ethic considers restrictions on choices based on moral duties (Wilber 1991) and decisions or actions are right or good if they conform to a relevant principle, rule or duty (Etzioni 1988: 12; McCain 1991). The goodness or moral status of an action is not determined by its consequences, but instead by the intention (Etzioni 1988: 12).

point out that the only reason the recovery program is included as a constraint is because humans yield some payoff from the recovery program or species survival (Finnoff and Tschirhart 2003a: 163). Thus, the ultimate objective is human welfare as described by a welfare function. Their choice to use a constraint for the recovery program is due to the difficulty in obtaining accurate monetary benefits for the existence, recreational and scientific values of the endangered species (Finnoff and Tschirhart 2003a: 163). This is a practical consideration, rather than an ideological or ethical stance that economic values cannot be traded for ecological values, because value-monism is still apparent in the model. For example, a greater harvest value will still reduce the endangered species' optimal population down to the MVP. In addition, if society were to value the harvest enough, the recovery program would be scrapped or compromised. Thus, the consequentialist ethic underlying the model of endangered species management can justify the endangerment of the sea lion.

The management regime and species are also compromised by the ontological foundations of the model. By applying a general equilibrium model to an ecosystem, Finnoff and Tschirhart (2003a) transfer the reductionist socio-economic ontology of orthodox economics into the natural world. Thus, species and other elements of nature are viewed, like the rational economic agent of the social world, as isolated and independent beings maximising their welfare in a vacuum or closed system, an ontology ill-suited to examining the complexities of the natural world. For example, there are a multitude of factors that are left out of the ecosystem model, as readily accepted by Finnoff and Tschirhart (2003a:176-7), such as sea surface temperatures, subsistence hunting and 'numerous human activities' that impact Steller sea lion populations. This is not to mention the multitude of excluded species that affect the actual outcome of the ecosystem. In fact, their model predicts only 16.4% of the reduction in sea lion populations that occurred between 1980 and the mid-1990s; and the policy suggestion for recovery is the fairly obvious conclusion that, to cut mortality of the sea lion by half, pollock harvests would need to be reduced by roughly half (Finnoff and Tschirhart 2003a:177).

In addition, given the complexity of interactions between the biotic and abiotic worlds, it is not clear that the model explains the actual reduction of sea lions. While it explains a 16.4% reduction during the study period, the credibility of the explanation cannot be guaranteed because of the multitude of other factors absent from the model. The problem is that solving a system of simultaneous equations involving '18 equations for a set of nine energy prices and nine biomass demands' (Finnoff and Tschirhart 2003a:168) assumes a closed system of event regularities. A resource manager following the approach could undermine the very values being pursued if these event regularities are not an accurate representation of the natural ontology. For example, it is a straightforward thought experiment to imagine that increasing the pollock harvest to maximise economic welfare could lead to domination of the ecosystem by an invasive species that the sea lion does not like to eat. The invasive species could out-compete the Pollock, leaving little food for the sea lion and thereby causing its eventual demise and also a greatly reduced pollock harvest. Scenarios such as these are not modelled. Nor could they be. Fundamental uncertainty prevails over the relationships and interactions within ecosystems (McDaniel and Gowdy 1998:1462; Spash 2012: 45): by ruling out this fundamental uncertainty any orthodox model will likely lead to problems in practice.

The Noah's Ark Problem

The second model to be examined is the Noah's Ark problem originally formulated by the prominent economist Martin Weitzman, which was published in *Econometrica* (Weitzman 1998) and the *Journal of Economic Perspectives* (Metrick and Weitzman 1998), with earlier development in the *Quarterly Journal of Economics* (Weitzman 1992, 1993). The Noah's Ark problem, which has also been adopted by some conservation biologists,[2] concerns the allocation of scarce conservation funds to preserve endangered species. Noah represents a conservation decision maker devising a ranking procedure for boarding species onto the Ark (or allocating funds) to assist their survival. Each species takes up some of the limited space on the Ark, which is not big enough to accommodate all species. That is, each species uses some of the scarce economic resources and the total budget is not big enough to save all species.

Like the previous model, Noah is assumed to be maximising economic value, even though this is, in part, tied to a biological variable. There are

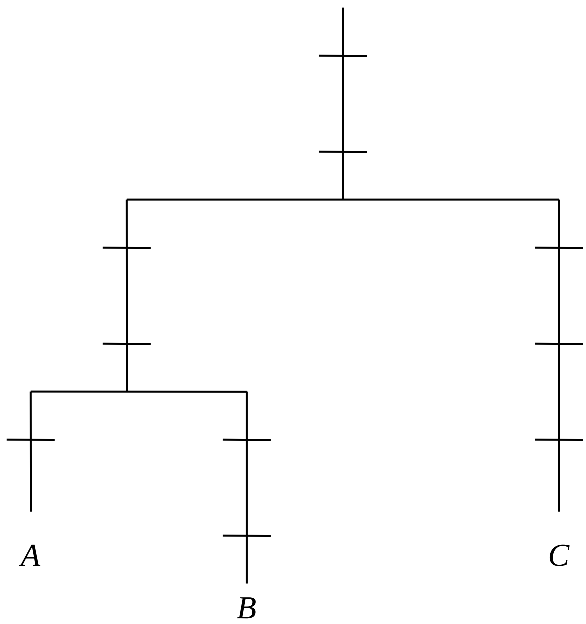
2 For example, Joseph *et al.* (2008) apply a similar framework to Weitzman (1998).

two aspects to the objective function. The first is the direct utility of the group of species boarded, reflecting their commercial value and their existence value or charismatic value to humans – ‘after all’, Weitzman (1998: 1280) says, ‘most of us like Pandas more than mosquitos’. The second is the diversity of the species boarded, with the value of diversity modelled as the branch length of a taxonomic tree. The more distinct a species is, the longer its branch length and the more valuable it is because it provides more information, a greater potential for future medicine and agricultural products, and because humans value variety. For example, in Figure 1, species *A* is the least valuable species because it is not very distinct from species *B*, whereas species *C* is the most distinct and valuable species.

In the Weitzman (1998) model, the first species boarded onto the Ark will be the one with the greatest expected marginal value per unit of conservation funds or the one with the greatest expected benefit to cost ratio. While the cost and recovery potential of each species is taken into account, the relatively large values for charismatic and highly diverse species means that they will inevitably be boarded before more common species needed for ecosystem functioning (Perry 2010). The likely outcome is a zoo on the Ark rather than a functioning ecosystem because a species’ value for ecosystem functioning does not correlate with either its distinctiveness or charismatic value.

The model highlights the ways in which the consequentialist ethic and the assumptions of atomism and stable event regularities which underpin orthodox economics can undermine biodiversity. The consequentialist ethic leads to different types of values being added together and traded off in a common metric. For example, the utility and diversity values are explicitly assumed to be commensurate (Weitzman 1998: 1280). In addition, the more costly a species is to save, the lower its rank. Thus, in the cost-benefit framework, the benefit of the species is traded off with lost economic resources – the opportunity cost of using resources for conservation. It is also instructive that the model neglects the ecological benefit of species in providing critical ecological functions for their ecosystems (Perry 2010). A species’ role in its ecosystem does not provide any direct monetary benefits or utility for humans. Therefore, ecological importance is not one of the welfare consequences considered. However, even if the ecological importance of a species could be included in the objective function and made commensurate with other values, the trade-off amongst these values and between these values and costs would continue, and biases would be expected in favour of charismatic, rather than ecologically valuable, species. This bias occurs because ecological values cannot be translated accurately into economic terms. Economic values do not reflect ecological realities, but rather are surface or superficial values regarding the objects of nature: they do not account for the ecological processes which underpin these surface economic values.

Figure 1: Branch Length of a Taxonomic Tree



Description: Each tick mark represents a unique gene for a species (*A*, *B*, or *C*) or a different book in the library (Weitzman 1998). Thus, species *C* is the most valuable because it contains three unique books (genes). If the least valuable species (species *A*) was to become extinct, species *B* would be the most valuable species.

In theory, it could be argued that it is possible to include ecological values within a consequentialist objective function. If all values were known, all probabilities of survival could be determined and all interactions amongst species were known with certainty – as assumed in Finnoff and Tschirhart (2003a) – a species with little direct utility or taxonomic distinctiveness could still be indirectly valuable once the known interactions were taken into account. However, fundamental uncertainty exists regarding these interactions and the true value of an interacting species cannot be determined. This creates an incommensurability problem (Aldred 2012: 1058) because the expected benefits and costs of saving a species can never be accurately counted and the decision can never be optimal (Quiggin 2005: 18).

Once again, the orthodox economic approach undermines the very values being pursued. For example, in Figure 1 above, if species *A* is needed for species *C*'s survival, then the higher ranking for *C* could lead to the extinction of that very species (Perry 1999). This anomaly is an ontological issue and proceeds from an inconsistent assumption. The model effectively assumes that, once the flood recedes, all the ecosystems of all the boarded charismatic species will be intact and available for the charismatic species to be placed back into. But if the flood has killed all non-boarded species and if ecosystems are collections of species, then the ecosystems will have disappeared and all the economically valuable species will then become extinct. Indeed, there are no ecosystems to be placed back into. In contrast, Noah would be better off creating at least one working ecosystem on the Ark which would support a few charismatic species but also the many invaluable species needed to provide the ecological underpinnings of life.

At its core, the problem in both models discussed is that nature is being constructed in atomistic terms in a similar way to the construction of socio-economic activity in orthodox economics. The worldview is one that is disconnected from reality because it treats actors as independent and free, while also assuming that the commodities they choose have no impact on the existence of other commodities. In other words, closed and regular systems are assumed. This leads to recommendations about resource management and endangered species that, unless luck is on our side, will undermine biodiversity. Because the natural world does not conform to the presupposed ontology, we need a different type of economic analysis that treats ecosystems as open systems where the whole is greater than the sum of the parts (Callicott 1986: 306; Spash

2012: 44). Unless economic methodology incorporates this holistic perspective of nature, where species and ecosystems are highly integrated and interdependent (Trepl 2012: 13; Warren and Cheney 1993: 100), policies run the risk of causing damages which compound rather than solve the biodiversity crisis.

Heterodox Economics and the Biodiversity Crisis

Utilising the insights derived from different schools of heterodox thought provides an alternative toolkit from which to conceptualise the causes of the biodiversity crisis, as well as the inherent difficulties associated with designing solutions. That is, rather than reducing the subject of economic study to a set of monist and *a priori* theoretical assumptions, heterodox economics enables a more realistic focus on the complexity that characterises ecological-economic processes in reality (see Hodgson 2001). In particular, drawing on the insights of different schools of thought enables recognition of important interrelated factors such as the role of political economic power relations in determining economic outcomes and the role of path dependence in maintaining these outcomes. Different theoretical assumptions regarding substitutability and the utilisation of alternative ontological assumptions together provide a perspective that is superior to orthodox economics. In what follows we seek to show that fruitful explanations and policies can be developed by drawing on heterodox economics due to its more ecologically-sympathetic ethical and ontological underpinnings. [3] We begin by discussing the causes of biodiversity loss before moving to a general policy approach.

To a heterodox environmental economist, the biodiversity crisis is not the inevitable or natural result of a market failure or externality. Neoclassicals define an externality as an involuntary action or something that occurs 'without particular attention to' others (Baumol and Oates

3 Heterodox economics is, of course, characterised by many schools of thought and the study of environmental policy and ecological processes will vary amongst the schools (for recent surveys, see: Marletto [2009], O'Hara [2009], Douai *et al.* [2012] and Spash and Ryan [2012]). In referring to 'heterodox economics' we focus on these key insights regarding power relations, non-substitutability and fundamental uncertainty or complexity that charcaterise most, but not necessarily all, heterodox schools of thought.

1988: 17). As Mishan (1971: 2; emphasis in original) states, it 'is not a deliberate creation but an *unintended* or *incidental* by-product of some otherwise legitimate activity.' In contrast, heterodox economics views environmental problems as systemic. Rather than being accidental, the biodiversity crisis is the result of an economic system which encourages the pursuit of profits at any cost and which, thereby, encourages overconsumption.

Thus, heterodox economics interprets the cause of biodiversity loss differently. The focus is on the underlying social structures or institutions that enable and constrain the activities of economic agents (Lewis 2004: 4-6). Society is seen as structured along hierarchical lines with different people having different rights, responsibilities and political economic capacities associated with their social positions. This produces vested interests because any individual in one of these positions has reasons and incentives for pursuing certain goals. Although humans have agency within social structures and can change them through time, it is the most powerful individuals and groups that have the greatest influence on the social structures that remain or change in the future (Lewis 2004: 9). Thus future social structures favour the vested interests of the powerful.

The explanation of socio-economic events such as biodiversity loss requires recognition of these social structures and vested interests. Rather than theorising biodiversity loss as a market failure, heterodox economists examine the practices causing the loss and uncover the social structures and vested interests underlying these practices (Lewis 2004: 10; Spash 2012: 44). For example, in the case of the Steller sea lion, the harvesting of its prey species has an important influence on its fitness or viability. However, there are many other human practices that impact the sea lion's viability, such as the use of fossil fuels which cause oil spills, global warming and the subsequent changes in weather patterns, recreational hunting, agricultural runoff, on-shore industrial waste and the like. These practices may affect the sea lion directly or indirectly through its various food chains. For each of these practices, the social structures that facilitate them are underpinned by the inherited anthropocentric worldview that humans are above nature. This is reflected in the fact that our social positions are primarily defined in terms of rights and responsibilities to other humans. While humans also have rights and responsibilities to some animals, this diminishes as we move through a hierarchy from mammals to birds to fish to reptiles to amphibians and so on. Moreover, rights and responsibilities to the interconnections that underpin nature are further down in this hierarchy if they exist at all. Thus, in protecting the interests of their social positions, humans will inevitably impose upon biodiversity. From a political economic perspective, these vested interests include the incentives of capitalists to make profit and increase wealth at any cost and the need for conspicuous and invidious consumption (Veblen 2007 [1899]). Biodiversity will not be adequately protected by relying on new price incentives and biodiversity markets while these vested interests remain. Price incentives may change actions at the margin but they will not address the root cause, a system grounded in the pursuit of profits.

Heterodox economics is also more open to non-substitutability and incommensurability, a fundamental requirement for developing policies to reverse biodiversity loss. In heterodox economics, there are limits to substitution at the theoretical level, with preferences generally seen as being lexicographic. From this perspective, substitution can only occur within distinct needs, such as hunger or thirst, and there is a place for moral obligations (Lavoie 2009: 142). More generally, heterodox economics follows a duty-based ethic with an emphasis on full-employment, a guaranteed income, social provisioning of essential services such as education and health care, and equitable income distribution. Thus, heterodox economics is more amendable to multiple, incommensurable objectives (Perry 2013). While, traditionally, heterodox economists have not focussed sufficiently on the environment (Mearman 2005; Spash and Schandl 2009: 13; Perry 2013), an ecological dimension can – and should - be added to current heterodox approaches to economic activity and policy. Following Aldo Leopold's (1949) Land Ethic, this ecological constraint could be framed as follows: humans must always maintain the resilience and integrity of ecosystems (see also Pelletier 2010: 1888).

Heterodox economics embraces fundamental uncertainty, which results from an acceptance of open systems and historical time. Fundamental uncertainty also leads to an acknowledgement of irreversibility, irreplaceability and incommensurability (Aldred 2012: 6, 9, 16-7) which is fundamentally required for a biodiversity crisis to be recognised. In general, heterodox economics is more amenable to conceptualising the natural world, like the social world, as complex with non-linear processes and where the whole is greater than the sum of its parts. This leads to an emphasis on path dependence and cumulative causation which are important elements of any biodiversity policy. For example, compromised food chains due to habitat loss and invasive species have uncertain impacts that may not be resolved for many generations. Working to correct biodiversity loss problems in the current period requires an acknowledgment of these cumulative forces.

As heterodox economics embraces uncertainty, the precautionary principle necessarily becomes a critical element in policy to halt the loss of biodiversity. As applied to biodiversity loss, the precautionary principle can be stated as follows:

> Where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat (Convention on Biological Diversity 1992: 1).

The precautionary principle incorporates a different ethic because it implies a duty to protect the environment and biodiversity even when there is not full certainty that the negative impact will occur.

However, despite its inclusion in many laws and conventions (McIntyre and Mosedale 1997; Vanderzwaag 2002; O'Riordan and Jordan 1995), the precautionary principle has been difficult to operationalise (O'Riordan and Jordan 1995) and is beset by criticism (Sandin *et al.* 2002). One way to operationalise the principle, however, is to use the minimax approach (Gardiner 2006: 45; Aldred 2012: 10). That is, in a development versus preservation decision where uncertainty prevails, the right decision is the one that minimises the maximum loss or the alternative with the best 'worst-case' outcome. In contrast to cost-benefit analysis, this affords more protection for biodiversity because tipping points and feedback effects are taken into account and the preservation option may minimise the maximum loss.

Yet the minimax approach still seems to reflect a consequentialist ethic because the worst case outcome of the development option is compared to the worst case outcome of the preservation option. Instead, we suggest reemphasising the implied duty-based ethic of the precautionary principle and using this as an overriding framework for decision making. When combined with the ecological constraint that humans must always maintain the resilience and integrity of ecosystems, the precautionary principle for heterodox environmental economics becomes:

> When there is uncertainty regarding the impact of an economic action or policy on biodiversity and natural systems, we must

> take precaution by ensuring the integrity and resilience of ecosystems.

The result is a stronger duty to protect ecological integrity and a treatment of the cause, rather than the symptom, of biodiversity loss. In contrast, orthodox economics will treat the symptom of biodiversity loss, the endangerment of species. For example, under consequentialism, ecological values will only ever outweigh economic alternatives when crisis has already occurred and policy will only be enacted to treat this symptom of biodiversity loss.

Of course, because the significant problem of vested interests remains, there would be a great deal of resistance to implementing programs based on this precautionary principle. In fact, the alternative cost-benefit framework is far more acceptable to powerful vested interests (Bromley 2004) because uncertain and unforseen ecological costs are not included in the calculation, which results in a bias towards economic growth. Thus, a political agenda arises from heterodox environmental economics. Advocacy for a countervailing power (Galbraith 1952) becomes integral to pushing for the precautionary principle and for controlling corporate interests that undermine biodiversity. Special interest groups and non-government organisations may serve this function but these usually remain small relative to the corporate interest. Heterodox economics therefore emphasises the need for the state to actively encourage effective cooperative action amongst environmental groups (Pressman 2007: 80; Perry 2013). In addition, the state must itself counter corporate vested interests rather than simply implementing post-crisis adjustments to resource management.

Conclusion

We have argued that orthodox economics cannot adequately explain the biodiversity crisis and that its preferred policies cannot solve it. Because orthodox economics conceptualises economic behaviour atomistically and ignores the guiding and limiting social structures, its characteristic policy suggestions will ignore social structures and associated vested interests. ‘Getting the prices right’ may adjust actions at the margin but does not change the structures that guide actions and cause biodiversity loss. The consequentialist ethical framework underpinning orthodox economic policy is also unsuitable for the issue of biodiversity loss because it implies value-monism, which allows incommensurable ecological values to be traded off with economic values. Orthodox theory also presupposes atomism in nature which leads to the denial of ecological complexity. The environment must be viewed holistically because the whole is greater than the sum of its parts. Only then will biodiversity loss be adequately understood and addressed.

We suggest that heterodox economics provides a more fruitful set of tools for analysis when addressing the biodiversity crisis. It involves a duty-based ethic and therefore it embraces incommensurable values. Heterodox economists also emphasise open systems and the fundamental uncertainty inherent to any analysis of natural systems. Moreover, heterodox economics recognises the vested interests in the existing social structures which precipitate biodiversity loss. We therefore suggest the precautionary principle and a pre-emptive approach to halting biodiversity loss as appropriate guides for economic policy. Finally, we encourage heterodox economists to actively engage with these conservation issues.

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