Appendix 4.2

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1 Ecosystem changes

Changes are often attributed to human influence (as in the case of global warming, Intergovernmental Panel on Climate Change 2007, and altered marine systems, Halpern *et al.* 2008). Change is one of the most documented aspects of ecosystems (Christensen *et al.* 1996, Colborn *et al.* 1997, MEA 2005a,b, Pauley *et al.* 1998, Silver and DeFries 1990, Turner *et al.* 1990, Woodwell 1990; World Conservation Monitoring Centre 1992; Vitousek *et al.* 1997). Changes that ecosystems experience include the influence of humans (Liu *et al.* 2007, Moran 2006, Steffen *et al.* 2004)—often seen as directly correlated with human population (Brashares *et al.* 2004). As part of such change, the patterns among species (seen in altered species frequency distributions) represented in ecosystems are altered. Such changes in degraded or stressed ecosystems are numerous and serve as examples of currently recognized ecosystem-level traits. Changes in the means of these distributions are often reported in the literature as a simple holistic measure of ecosystems. References that provide summaries or overviews of such changes are found in Barrett and Rosenberg (1981), Calow and Berry (1989), Cracraft and Grifo (1999), Fearnside (1990a), Freedman (1989), Gray (1989), Haskell *et al.* (1992), Lovejoy (1985), Mark and McSweeney (1990), Odum (1981, 1985), Rapport (1989a,b,c), Rapport *et al.* (1985), Sampson and Knopf (1994), Turner *et al.* (1990), Woodwell (1990), and World Conservation Monitoring Center (1992).

Ecosystem characteristics are interrelated such that changes in one are often interpreted to imply changes in another. Examining the variety of ecosystem characteristics that have been identified help us grasp their contribution to ecosystem structure and function. In this regard, structural properties of ecosystems seem to be more vulnerable to disruption than are functional characteristics (Odum 1985). All measures behind the conclusions in the literature listed below are based on ecosystems spatially defined by the observer. This is in contrast to what would be observed across the union of the geographic ranges of component species (e.g., those overlapping a particular point, or the range of a particular species).

Structural change includes change in the shape of any species frequency distribution. The number of species (area under species frequency distributions when expressed as numbers rather than portions) is one structural characteristic. Stressed ecosystems have been documented to lose species numbers (an ecosystem can lose a species by a reduction or shift in its range). When this happens the composition of remaining species often changes (Freedman 1989, Gray 1989, Hawksworth 1990, Myers 1989, Odum 1985, van der Maarel 1975). Changes in diversity in response to stress also include losses of genetic heterogeneity (Freedman 1989, Grassle *et al.* 1990, Gray 1989, Haskell *et al.* 1992, Karr 1992, Loya 1990, Lugo and McCormick 1981, Moore 1983, Rapport 1989a, Rapport *et al.* 1985, Woodwell and Houghton 1990). On occasion, stress results in an initial increase in species numbers before declines are observed.

During disruptive influence, more species are lost among the higher trophic levels and increases are occasionally observed among low trophic levels such that trophic chains shorten and mean trophic level drops (Odum 1985, Ulanowicz 1992, Yan and Welbourn 1990). Other interspecific dependency

also declines as exemplified by the loss of species that exhibit symbiotic interactions, specialization (Davis 1990, Karr 1992, Odum 1985, Pimentel *et al.* 1992, Sharitz and Gibbons 1981, Woodwell 1970). Changes in rates of decomposition also occur (Freedman 1989, Gray 1989).

Increased frequency of diseases and parasites (Gray 1989, McMichael 1993, Odum 1985, Rapport 1989a, Specht 1990, Webster and Walker 2003) accompanied by declines in measures of species-level health (Pimentel *et al.* 1992, Westman 1990b) have also been associated with ecosystem disturbance (see McMichael 1993, for a history of the awareness of human diseases and ecosystem disturbance).

Other (related) forms of ecosystem degradation involve shifts in composition toward smaller species (Gray 1989, Haskell *et al.* 1992, Odum 1985, Rapport 1989a,b, Woodwell 1970, Yan and Welbourn 1990), including reductions in the size of individuals within species (Odum 1985, Rapport 1989a). Most such changes are related to the increased predominance of small-bodied, *r*-selected species, pests, and weedy species and loss (including extinction) of large-bodied species (Bormann 1990, Gray 1989, Kerr and Dickie 1984, Odum 1985, Rapport 1989b, Rapport *et al.* 1985, Regier 1973, Specht 1990, Westman 1990b, Woodwell 1970, 1990, Woodwell and Houghton 1990, Yan and Welbourn 1990).

Various population-level characteristics of species undergo changes in disturbed ecosystems. At the ecosystem level, the mean level of population variability increases as a form of destabilization (Apollonio 1994, Gray 1989, Rapport 1989b, Rapport *et al.* 1985, Regier 1973, Regier and Hartman 1973, Rosenzweig 1971, Woodwell 1970, Yan and Welbourn 1990). Some of this may relate to increased mortality rates (Odum 1985). Humans are not immune to the effects of ecosystem change (e.g., Redman 1999).

Frequency distributions of density and population size are altered (Harmsen 1983). Populations for some species become reduced (Valiela 1990). Exceptions include small-bodied pests and pathogens as mentioned above. Changes similar to reductions in population size occur through changes in the spatial distribution of biomass (Freedman 1989, Lugo and McCormick 1981), and numbers of species in various range size categories (Mark and McSweeney 1990, Specht 1990).

The physiological or metabolic nature of ecosystems also change in response to various influences. As examples of functional aspects of ecosystems, these attributes may not be altered as much as structural properties. This may be explained by changes within the altered system wherein the switching of categories among species in structural change serves partially to compensate for changes that would otherwise be observed in total ecosystem-level rates.

Frequency distributions of productivity levels (including efficiency of photosynthesis) are altered such that mean productivity declines with stress (Freedman 1989, Gray 1989, Haskell *et al.* 1992, Lugo and McCormick 1981, Naeem *et al.* 1994, Odum 1981, Rapport 1989b, Sharitz and Gibbons 1981, Woodwell 1970). Typically, community-level metabolism declines (Freedman 1989, Odum 1985, Rapport *et al.* 1981, 1985). The efficiency of energy resource use declines (Odum 1985).

Other frequency distributions that respond to stress include those for nutrient cycling, nutrient content, and contributions to system totals for these dynamics. Specific rates at which nutrients (including carbon and oxygen) are cycled usually increase (Freedman 1989, Lugo and McCormick 1981, Naeem *et al.* 1994, Odum 1985, Rapport *et al.* 1981, 1985, Vitousek *et al.* 1981). As a result, changes in nutrient pools are observed (Haskell *et al.* 1992, Rapport 1989b, Rapport *et al.* 1985). These are usually losses, especially through increased rates of loss (Freedman 1989, Odum 1985, Rapport *et al.* 1985, Woodwell 1970). In contrast, in polluted ecosystems, there is a shift toward higher occurrence of species with large loads of toxic materials, along with declines in ability to detoxify (Rapport 1989a, Rapport *et al.* 1981).

When ecosystem structure and function are modified, new selective pressures arise such that coevolutionary dynamics within ecosystems are altered (e.g., Stenseth 1989). Evolutionary changes occur within species subject to direct influence of human activities (e.g., fishing, pesticide use, antibiotics; Bloom and Murray 1992, Blythe and Stokes 1993, Brown and Parman 1993, Cohen 1992, Curson 1989, Garrett 1994, Grey 1993, Kirkpatrick 1993,

Lappe 1994, Law and Rowell 1993, Law and Grey 1989, Law *et al.* 1993, Levinton 1992, Nelson and Soulé 1986, Neu 1992, Orians 1990, Pimentel *et al.* 1993, Policansky 1993a,b, Reznick 1993, Rijnsdorp 1993, Rowell 1993, Ryman and Utter 1987, Schaffer and Elson 1975, Slatkin 1983, Smith *et al.* 1991, Sutherland 1990, Trippel 1995).

When one species undergoes evolutionary change it produces new selective pressures to which other species respond. These result in evolutionary ripple effects and can be initiated by human influence. As Jordano (1987) indicates, little attention has been given to such dynamics especially in comparison to the attention historically paid to ecosystem mechanics (e.g., predator-prey or consumer-resource interactions). Such evolutionary changes are observed (see Grime 1989). Some are significant enough to result in extinction as one of the reactions to ecosystem change (Myers 1989, van der Maarel 1975). Such extinctions could easily be the result of increased population variability or any number of the many other changes observed for ecosystems under stress as listed above (e.g., declining health of component species, Westman 1990b).

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