CHAPTER 9

Valuing dragonflies as service providers

John P. Simaika and Michael J. Samways

Overview

Valuing the services provided by ecosystems and their components is emerging as a new, practical tool for conservation of biodiversity. One such framework for quantifying the components of biodiversity and their attributes that are important for the diversity of ecosystem services is the service providing unit (SPU). This framework, which is additive to other, current frameworks, provides a conceptual link between ecosystem services and the role of populations of different species in providing these services. Any particular SPU provides a given service at a given spatial or temporal scale. Service provision may benefit humanity either directly or indirectly. Dragonflies provide several ecosystem services to humanity at the population level. Their role as SPUs encompasses most of the 28 ecosystem services, directly or indirectly, as recognized by the Millennium Ecosystem Assessment, in the categories of provisioning, cultural, supporting, and regulating services. Odonates lend themselves well as SPUs, as they are well known taxonomically, conspicuous, and flagships of freshwater conservation. Dragonflies provide enormous cultural benefit to humans, as shown by much visual and literary art, and the many worldwide recreational parks, trails, and field guides dedicated to this taxon alone. Service provision by dragonflies sometimes can be quantified easily. We provide examples of this in pest control and riparian restoration. The latter has been a huge success for South African dragonflies, with the populations of many species, including Red Listed ones, stabilizing and even increasing. Indeed, dragonflies are now being widely used as habitat quality indicators. On the negative side, odonates may also have adverse effects on services, thereby reducing their value, as for example with pollination. The SPU concept, as a value metric, has considerable currency with dragonflies, and there is merit in investigating its application to other invertebrate taxa and ecosystems.

9.1 Introduction

Biodiversity is the diversity of genes, species, and ecosystems. Efforts to conserve biodiversity have increased substantially in recent years, as a reflection of the realization that our well-being depends not only on conserving, but also using, biodiversity wisely. To do so depends in part on how we value that biodiversity.

In its simplest form, biodiversity value may be divided into utilitarian value (of use to humans) and intrinsic value (not necessarily of use to humans). Although we focus here on dragonflies as an entity, they are essentially no different from any other group of organisms, in terms of their *intrinsic* value. Furthermore, we should bear in mind that dragonflies are not a finite ecological box, but for policy-makers. The current approach requires that for biodiversity to be conserved, it must pay its way. This is not only an economic issue but also one of service provision (Millennium Ecosystem Assessment 2005; Bishop *et al.* 2007). The utilitarian standard set by the Millennium Ecosystem Assessment can be seen as providing the vital conceptual link between individual species and their contribution to the provision of ecosystem services. In addition, this link can also be translated into an economic measure. For example, Losey and Vaughan (2006) estimate that wild insects that control pests, pollinate flowers, bury dung, and provide nutrition for other wildlife are worth US$57 billion per year in the USA alone.

The European Union's Co-ordination Action Project RUBICODE (Rationalising Biodiversity Conservation in Dynamic Ecosystems; www.RUBICODE.net) is now exploring this predominantly utilitarian approach. The project's aim is to review and develop concepts of dynamic ecosystems and the services that they provide. Those components of biodiversity which provide specific services to society are being defined and evaluated to increase our understanding of the value of biodiversity services, as well as the cost of losing them. This will give decision-makers a more rational base and will help the understanding of the need for adequate conservation policies, which are essential to halting biodiversity loss.

Building on the Millennium Ecosystem Assessment (2005), a new approach is also being developed, which was first articulated by Luck *et al.* (2003). This novel approach uses the concept of service providing units (SPUs), which focuses on what biodiversity does for humanity, using quantifiable services. These levels may be the populations of single species but they may also be the populations of several species. The SPU concept identifies the important species populations for service provision, as well as the important attributes of those populations (size, temporal or spatial distribution, etc.). The reasoning behind this approach is that it translates threats to, and value of, biodiversity into tangible and quantifiable factors for use by policy-makers. As well as one or more species contributing to a service, they may also contribute to more than one service.

Conceptually there is also the converse of the SPU, where certain populations of certain species can reduce a service. Such populations are termed service antagonizing units (SAUs; see www.RUBICODE.net). These concepts can be illustrated with, for example, the service of pollination. The SPUs are the right pollinators in sufficient numbers to carry out the service; that is, pollination. Yet these pollinators may be subject to ameliorating factors such as infestation by the *Varroa* mite, a bee parasite, which, in sufficient numbers, may reduce provision of the service, and so are an SAU. When communities are considered, there is a whole host of species which can alter the dynamics of food webs (Memmot 2000). In the final analysis, the quantity and quality of the service provision depends on the sum of the SPUs minus that of the SAUs.

As research into service provision is just beginning, it is difficult to quantify accurately many of these services. Nevertheless, it is the aim of RUBICODE to build upon what is known to date. In keeping with the theme of this book, dragonflies as model organisms for ecological and evolutionary research, and because this taxon is being considered in contemporary SPU research, it is appropriate to review the topic.

9.2 Dragonflies and ecosystem services

As the Millennium Ecosystem Assessment (2005) is an authoritative document, it is a valuable platform from which to launch a discussion of the significance of dragonflies in service provision. The Millennium Ecosystem Assessment recognizes 28 ecosystem services to humans, in four distinct categories: provisioning, cultural, supporting, and regulating services. These services can be applied at the population level (Table 9.1). They could be considered of direct benefits to humans, and thus species or populations providing these services are SPUs. As dragonflies are top predators, only certain services are, by definition, applicable to them.

9.2.1 Positive contributions (service provision)

9.2.1.1 Provisioning services

Provisioning services are the products obtained from ecosystems (Millennium Ecosystem Assessment invertebrate biology have often led to a better understanding of mammalian biology. For example, the discovery and dissection of mechanisms regulating innate immunity pathways in mammals were based on knowledge gleaned from *Drosophila* (true flies). Schilder and Mardens (2006) hope that pathways involved in the development of metabolic abnormalities may be similarly homologous, which opens the way for the use of non-mammalian systems as an additional tool to study causes and treatments for metabolic diseases such as diabetes and obesity.

Dragonflies also have ornamental value. As with butterflies, they are often preserved for display in cabinets, although their main value is as motifs on household items.

Dragonflies are not a staple food (like rice) that nations depend on. Nevertheless, they are often enjoyed as a delicacy or as an ingredient in main dishes in a variety of cultures in Asia (e.g. China, Japan, India), Africa (including Madagascar), and the Americas (Mexico) (Corbet 2004). For example, on Bali, dragonflies are fried in coconut oil and served with vegetables (Hardwicke 1990).

Dragonflies are being used more extensively in genetic studies, particularly to elucidate aspects of their conservation. Thompson and Watts (2006), for example, using genetic studies, showed that for the European damselfly *Coenagrion mercuriale*, it was not habitat loss that is the main concern but limited movement, indicating that sites for conservation must be placed close together.

9.2.1.2 Cultural services

Cultural services are the non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences, including cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, recreation, and ecotourism (Table 9.1) (Millennium Ecosystem Assessment 2005). Dragonflies have cultural significance (Corbet 2004). For example, to the Navaho Indians, odonates symbolize pure water. Traditionally known as the 'invincible insect', the dragonfly was a favourite symbol of strength among Japanese warriors, and the old name for the island of Japan (Akitsushima) means 'dragonfly island' (Kritsky and Cherry 2000). Dragonflies are thought to possess medicinal properties and are used by practitioners of traditional medicine in China and Japan (Asahina 1974).

Along with butterflies, dragonflies arguably are the most significant in terms of recreational service. They are especially appreciated by the Japanese, where Odonata reserves or parks are well established, and new areas rehabilitated to help promote conservation awareness (Figure 9.1) (Primack *et al.* 2005). The recreational value of Odonata is also increasingly recognized by other developed nations, as the burgeoning number of field guides, associations, and websites would suggest (Lemelin 2008). Many parks worldwide feature dragonfly

Figure 9.1 Sophisticated infrastructure at the Nakamara Dragonfly Reserve in Japan, emphasizing the cultural significance of these insects in this region.

trails, not necessarily for threatened species, but rather for enjoyment of the insect subjects and to increase awareness (Niba and Samways 2006). In South Africa, for example, a dragonfly trail has been established (Suh and Samways 2001).

9.2.1.3 Supporting services

Supporting services are those that are necessary for the production of all other ecosystem services. They differ from the other services in that their impacts on humanity are often indirect or occur over a very long period of time, whereas changes in the other categories have relatively direct and short-term impacts on people (Millennium Ecosystem Assessment 2005). These services include soil formation, photosynthesis, primary production, and nutrient and water cycling (Table 9.1). Dragonflies contribute to nutrient cycling in that they are top predators in vertebrate-free habitats, both as larvae and adults. Dragonfly larvae prey on other insects including other odonates, fish fry and eggs, amphibian larvae, crustaceans, molluscs, flatworms, and leeches (Corbet 2004). Adults, like their immature counterparts, are also predators, feeding on a variety of insects including other dragonflies. For example, Pritchard (1964) reports that at least 79% of prey items available to Aeshnidae, and 90% to Libellulidae, are Diptera, followed by 58% and 20% Coleoptera, respectively. Pritchard also reports that large Aeshnidae consume Trichoptera and other Odonata. Overall, however, Diptera are the major prey of odonates (Corbet 2004). Dragonflies have very wide dispersal capability, and they introduce nutrients from aquatic ecosystems to terrestrial ecosystems. For example, there may be over 1.2 million individuals partaking in the large annual migration of *Anax junius* adults in North America (Russell *et al.* 1998). These migrations are now known to have great similarity with songbird migration strategies (Wikelski *et al.* 2006).

Both larval and adult dragonflies have associations with other organisms, which relates to the definition of supporting services in the Millennium Ecosystem Assessment. These supporting services have great variety and come from numerous taxa; thus only some are mentioned here briefly. Associations include, apart from predators, commensals, mutualists, pathogens, and parasites. On dragonfly larvae, the associated commensal organisms may include diatoms, rotifers, molluscs, and other insects. Water mites are commensal on larvae, but parasitic on adults (Corbet 2004). An interesting mutualism involves an alga and the damselfly larva, *Mecistogaster ornata*, whereby the larva provides substrate for the alga and postures itself to enhance the photosynthetic activity of the alga, increasing the oxygen concentration around its respiratory surfaces (Willey *et al.* 1970).

Parasites of larval and adult dragonflies include organisms from the Phyla Protozoa, Platyhelminthes, Aschelminthes, and Arthropoda. Of special interest are the trematodes, several species of which infest poultry and humans. These infestations are mediated by dragonflies, as described in Section 9.2.2. Adult dragonfly commensals are varied. These include pseudoscorpions, biting lice, wasps, milichiid flies, algae, and microorganisms. Dragonflies appear to be susceptible to some well-known fungal insect pathogens, including *Claviceps* and *Cordyceps* (Corbet 2004). By far the most conspicuous and prevalent parasites are the ectoparasitic water mites (Hydrachnida) (Smith 1988). Water mites are ubiquitous on dragonflies wherever there are eurythermic waters that are lentic or slow-flowing, and usually permanent, or temporary. Damselflies are parasitized more often than dragonflies (Smith 1988). Furthermore, common, widespread odonate species are more susceptible to mite infestation than sympatric rare and threatened ones, indicating the significance of species traits (Grant and Samways 2007b).

9.2.1.4 Regulating services

Regulating services are the benefits obtained from the regulation of ecosystem processes (Millennium Ecosystem Assessment 2005). They include regulation of air quality, climate regulation, water regulation, erosion regulation, water purification and waste treatment, disease regulation, pest regulation, pollination, and natural-hazard regulation. Dragonflies are only very minor components as drivers of climate regulation, as their total biomass is relatively small. However, they are highly responsive to climate change, in terms of both geographic range change (Aoki 1997; Ott 2007) and phenology (Hassall *et al.* 2007).

Being a top predator, dragonflies may have some impact on invasive organisms lower in the food chain, including honey bees in Florida (Wright 1944). Dragonflies also have potential in pest regulation. Both larval and adult dragonfly stages may be used in pest control. For example, as explained in more detail below (Section 9.3.1), an experiment in a village in Myanmar (Burma) demonstrated that larval odonates of *Crocothemis servilia* could be used to control larvae of *Aedes aegypti*, a vector of dengue fever (Sebastian *et al.* 1990). Another example for pest control comes from several Asian countries, where various species of damselflies breed in rice fields. The damselflies consume large numbers of stem borers and leafhoppers from among the leaves of rice plants. Dragonflies are among the most effective predators of rice pests, partly because their density among the rice plants increases as the growing season advances (Nakao *et al.* 1976). According to Yasumatsu (in Corbet 2004), in some rice fields where dragonflies occur, about 80% of farmers use no pesticides.

Dragonflies are increasingly used as bioindicators of freshwater health and ecological integrity (see Chapter 7 in this volume). They compare very species attack bee colonies of apiaries, but also wild colonies and solitary pollinators. Wright (1944) reports that bee colonies of apiary yards along the Mississippi River in Louisiana were severely reduced by predation by large aeshnids. Reportedly, where normally 75–85% of queens would return to the yard after a nuptial flight, only 5% were doing so in the summer of 1941. Predation on worker bees was also severe. Predation on pollinators by some dragonflies, such as *Coryphaeschna ingens*, a species occurring in Florida, is so severe that it is locally known as the 'bee butcher'. Apparently this species has made queen rearing unprofitable and impracticable in parts of the south-eastern USA (Corbet 2004). The effect of predation on pollinators is measurable not only with domesticated populations for commercial use, but also with wild populations (Knight *et al.* 2005; discussed in greater detail in Section 9.3.2).

Dragonflies may serve as intermediate hosts of a number of parasites, including trematodes. This includes a fluke, *Prosthogonimus* sp., that causes severe inflammation in the oviducts of birds, production of abnormal eggs, and peritonitis that is normally fatal. The fluke also affects poultry. When found in eggs, a farmer's produce is ruined. Birds are usually infected in spring or early summer, and contract the parasites by eating larval or adult dragonflies. At least 13 orders of birds are known to be definitive hosts for *Prosthogonimus* sp. To prevent infection of stock by 'dragonfly disease', poultry farmers in eastern Europe keep their poultry away from water's edge when large numbers of dragonfly larvae emerge, and shut the birds away when large numbers of migrating adults appear (Street 1976). In south-east Asia, humans too, may be susceptible to trematode infection vectored by dragonflies. Humans are definitive hosts for two species, *Phaneropsolus bonnei* and *Prosthodendrium molenkampi*. People are infected with these trematodes by ingestion of larvae, which are eaten raw or ground up and added to other foods (Manning and Lertprasert 1973). Infection can be avoided by cooking the larvae before eating them.

9.3 Quantifying SPUs and SAUs

The value of the SPU lies in its identification and quantification of *changes* in population *levels*, and where these changes make a difference to service provision, whether positive or negative. Identification of quantitative links between components and service provision then become crucial for guiding the management of services. This is of importance to policy-makers and land managers as it facilitates specific rather than vague management guidelines. We now look at three examples, two positive and one negative, in more depth.

9.3.1 Dragonflies as SPUs in pest control

Certain dragonfly species and population levels have great potential in pest regulation, as demonstrated by a pilot study described in Sebastian *et al.* (1990). In an experiment in a village in Yangon, Myanmar, Sebastian *et al.* (1990) used larval odonates of *Crocothemis servilia* to control larvae of *A. aegypti*, a vector of dengue fever. The libellulid *C. servilia* lends itself well for the task in pest control, as it is a eurytopic species and easily reared in captivity from egg to adult. Gravid females of this multivoltine species are available throughout the year, ensuring a continuous supply of eggs for rearing. Also, the larvae of *C. servilia* survive well in large containers for several weeks on a low diet.

In their pilot study, Sebastian *et al.* (1990) established a treatment and control area. In the former, three to four dragonfly larvae were released into variously sized containers that the home-owners in the community used to collect water for drinking and other household usage. They found that at the first evaluation, half a month after the augmentative release, *A. aegypti* larval indices had fallen by 46–86%, and at the second evaluation, one full month after augmentative release, by 77–96%. The indices continued to fall to negligible levels as the experiment continued. These findings are consistent with earlier, preliminary results, that two half-grown libellulid larvae can kill virtually all mosquito larvae in a drum of 90-litre capacity in 4–9 days, depending on the number of mosquito larvae initially present (Figure 9.2) (Sebastian *et al.* 1990).

9.3.2 Dragonflies as SAUs in pollination

In the case where dragonflies may act as SAUs, this can also be quantified. Recently, Knight *et al.* (2005) investigated how predation affects trophic cascades, both directly and indirectly, across ecosystems. The researchers set up predation experiments on pollinators, using dragonflies. In their experimental

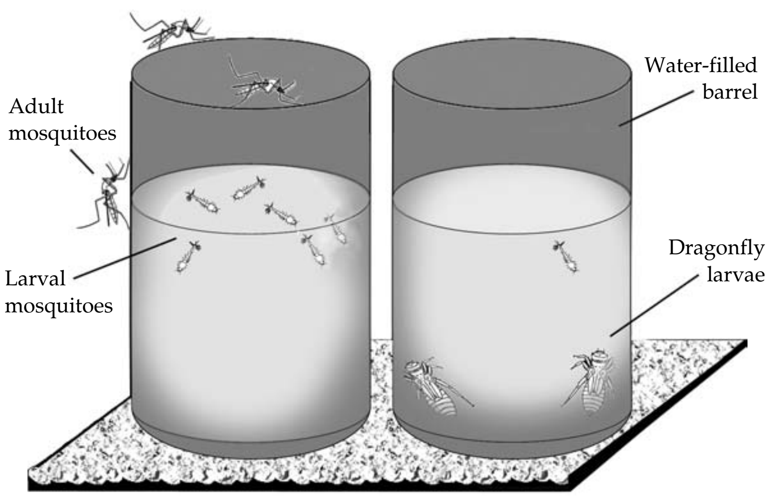

Figure 9.2 Stylized diagram illustrating the pest-control experiment by Sebastian *et al.* (1990) in a village in Yangon, Myanmar. Sebastian *et al.* (1990) used larval odonates of *Crocothemis servilia* to control larvae of *Aedes aegypti*, a vector of dengue fever. In the dragonfly-free barrel (left) mosquito larvae mature without predation pressure. However, with as few as two dragonfly larvae present, the mosquito population is severely decimated in as few as 4–9 days, depending on the initial number present in a 90-litre barrel.

Knight *et al.* (2005) also investigated the effect of fish on dragonflies and whether the cascading effect on pollinator visits influenced plant reproductive output (Figure 9.3). Plants near fish-free ponds were more than twice as pollen-limited than plants near ponds with fish. The strong linkages between consumers in aquatic and terrestrial ecosystems are not an isolated occurrence, and could have been demonstrated with other aquatic or semi-aquatic predators revealing a similar trophic cascade into terrestrial ecosystems.

9.3.3 Dragonflies as SPUs for riparian restoration

Benthic macroinvertebrates have been widely

sJWeh e r r

to overall stream condition (Smith *et al.* 2007). Arguably, the adult dragonflies are also fairly good surrogates of stream biodiversity in general. This is especially significant bearing in mind that freshwater systems are among the most threatened of any in the world (Naiman *et al.* 2006).

Without detailed studies focusing on a particular species, it is generally difficult to assess population levels of invertebrates. This is because they are often small, cryptic, and seasonal, making even Red List assessments difficult without considerable resources and some detailed knowledge of their biology (Samways and Grant 2007). This is despite many insect taxa in particular being excellent indicators of environmental health (McGeoch 1998). Dragonflies are among those sensitive taxa. They are large and conspicuous and have a range of sensitivities from one species to the next. Whereas certain individual species may be good indicators of landscape change (Sahlén 2006; Smith *et al.* 2007), and even global climate change (Ott 2007), it is really the whole assemblage and the relative change in its species composition which signals best any change in environmental conditions. Thus, we propose here that the SPU is the dragonfly assemblage.

The quantitative level at which the SPU operates is the nominal; that is, species presence or absence. However, species differ qualitatively in their response traits to river restoration and thus each species is given a Dragonfly Biotic Index (DBI). This is based on the sum of three sub-indices: (1) the size of the species' geographical range, (2) risk of extinction, and (3) its sensitivity to habitat change. Each sub-index has a score of 0–3, resulting in widespread and common habitat generalists scoring 0, and threatened, endemic habitat specialists scoring as much as 9. The scores relative to geographical distribution, threat level, and sensitivity are given in Table 9.2.

By far the greatest threat to South African dragonflies is from invasive alien trees, which block out sunlight and cause general deterioration of the river bank (Samways and Taylor 2004). Invasion is a key threat (Samways 2006), and lifting it results in an immediate recovery of even the rarest and most sensitive of endemics (Samways *et al.* 2005).

There has been ongoing and massive nationwide restoration of rivers in South Africa, known as the Working for Water Programme (Richardson and van Wilgen 2004). Its prime target has been the restoration of hydrology and to provide jobs. Biodiversity recovery was not originally high on the agenda, but as it turns out from the dragonfly studies, biodiversity has benefited enormously from this restoration activity. This is important, as South Africa has biodiversity hotspots (Myers *et al.* 2000). Although it was known that dragonflies are sensitive indicators for the success of this restoration programme at the local level (e.g. Clark and Samways 1996; Smith *et al.* 2007), it became clear after studies were done at larger spatial scales (e.g. Stewart and Samways 1998) that the use of dragonflies as SPUs could also be undertaken at the national scale (Grant and Samways 2007a). Thus we have a SPU that is easy to use and effective on

Table 9.2 Typical Dragonfly Biotic Index (DBI) scores for African dragonfly species. The DBI ranges from 0 to 9. It is based on the three sub-indices relating to geographical distribution, level of threat, and sensitivity to habitat change, with particular reference to invasive alien

Table 9.3 Biodiversity recovery at Disa Stream, Table Mountain, as measured by the Dragonfly Biotic Index (DBI) before and after removal of invasive alien plants.

Before		**After**	
Species	DBI	Species	DBI
Stream Hawker	4	Conspicuous Malachite	7
Cape Julia Skimmer	4	Marbled Malachite	8
Little Scarlet	3	Sooty Threadtail	7
Red-veined Dropwing	0	Palmiet Sprite	7
Navy Dropwing	0	Friendly Hawker	3
		Stream Hawker	4
		Mahogany Presba	8
		Cape Julia Skimmer	4
		Little Scarlet	3
		Red-veined Dropwing	0
		Navy Dropwing	0
Total DBI	11	Total DBI	51

Table 9.4 Biodiversity recovery at DuToit's River, Franschhoek Pass, as measured by the Dragonfly Biotic Index (DBI) before and after removal of invasive alien plants.

Before		**After**	
Species	DBI	Species	DBI
Sooty Threadtail	7	White Malachite	7
Mountain Sprite	4	Ceres Streamjack	9
Orange Emperor	2	Sooty Threadtail	7
Boulder Hooktail	2	Mountain Sprite	4
Cape Julia Skimmer	4	Mauve Bluet	9
Red-veined Darter	0	Stream Hawker	4
Navy Dropwing	0	Orange Emperor	2
		Boulder Hooktail	2
		Gilded Presba	8
		Mahogany Presba	8
		Yellow Presba	7
		Cape Julia Skimmer	4
		Red-veined Darter	0
		Navy Dropwing	0
		Jaunty Dropwing	1
Total DBI	19	Total DBI	72

multiple scales. Naturally, there are differences in the 'players' (particular species), yet the principle is the same wherever the SPU is applied. This emphasizes that whereas the SPU approach focuses on function and the services provided, it is essential also to recognize ecological integrity;

Table 9.5 Biodiversity recovery at White River, Bainskloof Pass, as measured by the Dragonfly Biotic Index (DBI) before and after removal of invasive alien plants.

Before		**After**	
Species	DBI	Species	DBI
Sooty Threadtail	7	Conspicuous Malachite	7
Mountain Sprite	4	White Malachite	7
Stream Hawker	4	Marbled Malachite	8
Orange Emperor	2	Sooty Threadtail	7
Boulder Hooktail	2	Mountain Sprite	4
Cape Julia Skimmer	4	Palmiet Sprite	7
Red-veined Darter	0	Stream Hawker	4
		Orange Emperor	2
		Common Thorntail	2
		Cape Thorntail	8
		Boulder Hooktail	2
		Rustic Presba	8
		Mahogany Presba	8
		Yellow Presba	7
		Cape Julia Skimmer	4
		Red-veined Darter	0
Total DBI	23	Total DBI	85

that is, species' identity and where they live (what Lockwood (2001) calls a sense of place).

Using the DBI is effective and easy, and all it requires is close-focus binoculars for species recognition. It can be applied to various streams and rivers. The service value can be calculated as the ratio of the sum of the DBIs after alien clearance to that before. For example, where the sum of the DBIs after clearance is 50, yet before it was 25, then the biotic recovery is 2. Translated into a percentage Biodiversity Recovery Score (BRS), this is 200%.

The great advantage of this BRS is that very high scores come out for streams which had previously lost their narrow-range and sensitive specialists, and have now been restored as a result of removal of the alien trees. Examples are given in Tables 9.3, 9.4, 9.5, and 9.6. The DBIs of the species used in the examples are given in Table 9.7. The massive BRS (464%) for Disa Stream on Table Mountain (Table 9.3) and the very high values for DuToit's River at Franschhoek Pass (379%; Table 9.4), and White River in Bainskloof Pass (370%; Table 9.5) are because these stretches of flowing water are in the centre of the Cape Floristic Region biodiversity

Table 9.6 Biodiversity recovery at Levuvhu River, Soutspansberg, as measured by the Dragonfly Biotic Index (DBI) before and after removal of invasive alien plants.

Before		**After**	
Species	DBI	Species	DBI
Dancing Jewel	1	Dancing Jewel	1
Goldtail	5	Common Threadtail	3
Common Threadtail	3	Painted Sprite	2
Painted Sprite	2	Kersten's Sprite	1
Kersten's Sprite	1	Slate Sprite	2
Swamp Bluet	1	Swamp Bluet	1
Boulder Hooktail	2	Orange Emperor	2
Two-striped Skimmer	2	Common Tigertail	1
Eastern Julia Skimmer	0	Boulder Hooktail	2
Portia Widow	1	Two-striped Skimmer	2
Round-hook Dropwing	0	Eastern Julia Skimmer	0
Riffle-and-reed Dropwing	3	Black-tailed Skimmer	1
Jaunty Dropwing	1	Portia Widow	1
		Broad Scarlet	0
		Little Scarlet	3
		Red-veined Darter	0
		Denim Dropwing	3
		Navy Dropwing	0
		Kirby's Dropwing	1
		Riffle-and-reed Dropwing	3
Total DBI	22	Total DBI	29

hotspot. This contrasts with the situation on the Levuvhu River in the Soutpansberg where there is only one national endemic species (albeit a sensitive one) and the BRS is comparatively low (132%; Table 9.6). The significant recovery of the Disa Stream is represented in Figure 9.4.

9.4 Critique of the SPU/SAU concept with respect to dragonflies

SPUs are essentially a way of quantifying service provision. As regards dragonflies, we may then ask whether the *quantity* of dragonflies matters to humankind. Furthermore, we may also ask whether the dragonflies contribute to the SPU concept.

There is no doubt that dragonflies play an enormous cultural role, but this is largely associated with their presence or absence, rather than their population levels. Yet in an era of rapidly declining

Table 9.7 Odonata species and their sub-indices reflecting the species geographical distribution (G), its extinction threat (T), and its sensitivity to habitat change (S). Each of the three sub-indices are on a scale of 0–3, and the sum of these three scores is the Dragonfly Biotic Index (DBI). Only those species featured in the examples given in this chapter are listed here.

Common name	**G**	**T**	**S**	**DBI**
Black-tailed Skimmer	0	0	1	1
Boulder Hooktail	0	0	2	2
Broad Scarlet	0	0	0	0
Cape Julia Skimmer	3	0	1	4
Cape Thorntail	3	2	3	8
Ceres Streamjack	3	3	3	9
Common Thorntail	0	0	2	2
Common Threadtail	0	0	3	3
Common Tigertail	0	0	1	1
Conspicuous Malachite	3	1	3	7
Dancing Jewel	0	0	1	1
Denim Dropwing	1	0	2	3
Eastern Julia Skimmer	0	0	0	0
Friendly Hawker	2	0	1	3
Gilded Presba	3	2	3	8
Gloldtail	2	0	3	5
Jaunty Dropwing	0	0	1	1
Kersten's Sprite	0	0	1	1
Kirby's Dropwing	0	0	1	1
Little Scarlet	1	0	2	3
Mahogany Presba	3	2	3	8
Marbled Malachite	3	2	3	8
Mauve Bluet	3	3	3	9
Mountain Sprite	2	0	2	4
Navy Dropwing	0	0	0	0
Orange Emperor	0	0	2	2
Painted Sprite	0	0	2	2
Palmiet Sprite	3	1	3	7
Portia Widow	0	0	1	1
Red-veined Darter	0	0	0	0
Red-veined Dropwing	0	0	0	0
Riffle-and-reed Dropwing	1	0	2	3
Round-hook Dropwing	0	0	0	0
Rustic Presba	3	2	3	8
Slate Sprite	0	0	2	2
Sooty Threadtail	3	1	3	7
Stream Hawker	2	0	2	4
Swamp Bluet	0	0	1	1
Two-striped Skimmer	0	0	2	2
White Malachite	3	1	3	7
Yellow Presba	2	2	3	7

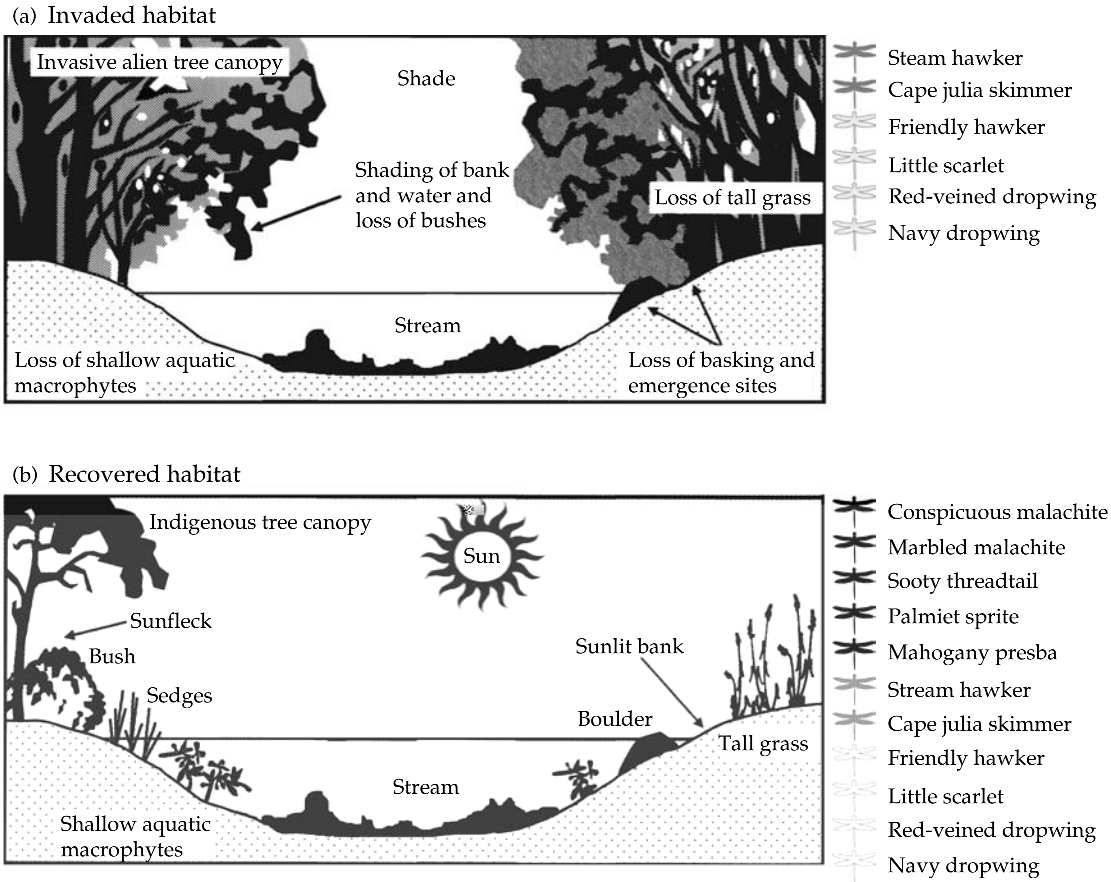

Figure 9.4 Dragonfly habitat invaded by alien trees (a) and recovery in rehabilitated habitat (b). In (a), the invasive alien tree canopy shades out the variety of indigenous grasses and bushes. This adversely alters the habitat structure, and also decreases the solar energy that adult dragonflies depend on. In recovered habitat (b), solar energy now penetrates indigenous tree canopy and allows grasses and bushes to grow. The indigenous habitat structures and increased solar energy now provide the habitat needed by rare, endemic habitat specialists and increase the diversity of the dragonfly assemblage. Stylized dragonflies represent the Dragonfly Biotic Index (DBI) as follows: extreme habitat generalists, DBI 0–3 (light grey); habitat generalists, DBI 4–6 (dark grey); habitat specialists, DBI 7–9 (black). Redrawn from Samways (2006).

biodiversity, presence also means healthy and robust populations (Bridle and Vines 2007). The presence of a population that is facing an extinction debt (Tilman *et al.* 1994) would be a population of concern.

At this point, we need to bring in the concept of intrinsic value. The reason for this inclusion is that arguably so long as the public at large is engaged with dragonflies, *any* dragonflies, that is enough to satisfy the cultural value. In such a case, only the real aficionados would be concerned whether or not it is a rare and threatened species. This is driven home when we consider theme parks that feature dragonflies. Normally the species to which the public are exposed are the common and widespread ones. Although this is good for being in touch with nature, it is doing little for the seriously threatened species to which the public is not normally exposed. We do not wish to see the 'extinction of experience', where people miss out to an increasing extent on their contact with nature, but there is a question of *quality* rather than *quantity* at stake here, where such parks should be instigated alongside conservation management of the threatened species at other locations (Samways 2007).

The three detailed examples given in this chapter give very different angles to service provision. The control of mosquitoes involves the deliberate introduction of dragonflies in particular quantities in artificial water bodies (Sebastian *et al.* 1990). Arguably this is not really what the SPU concept is about, as it is an artificial situation. Yet this might well be a representative example, as dragonflies are known to eat mosquitoes in natural ecosystems. Furthermore, it is common knowledge among odonatologists that many dragonfly species can be reared on mosquito larvae. The point that is brought home here is the possible consequences of *withdrawal* of a service (i.e. where dragonfly populations have been lost). This example illustrates that there is likely to be a huge amount of service provision in natural ecosystems that simply has not yet been quantified.

The example of dragonflies reducing pollinators (Knight *et al.* 2005) is very distinctly negative and, again, quantifiable. Interestingly, the fish that fed on the dragonflies were alien. Thus there is a situation here where an alien is improving a service provision. This is of course a violation of a sense of place (Lockwood 2001). Furthermore, this situation may well have other consequences such as loss of other macrobenthos. Alternatively, the plants benefiting from the increased predation of dragonflies by fish could, at least theoretically, increase in population level and in doing so impact on other, sympatric species of plants. What is clear from this example is that there are many possible ramifications when one starts to probe the changes in level of service provision.

The third example, very different from the other two, operates at the level of the assemblage. Dragonflies are clearly excellent indicators of riparian restoration where invasive alien trees are being removed. Yet the most sensitive species are the rare and threatened ones that occur in the global biodiversity hotspot, the Cape Floristic Region. Many of many insect species the population size, in terms of number of individuals, is difficult to measure, the Red-Listing process also works on measures of population size based on the extent of occurrence and area of occupancy (IUCN 2001). Thus the service is definitely quantifiable but in this case it uses both the number of species and the identity of particular species.

In summary, what the SPU/SAU concept does, as highlighted by these dragonfly examples, is enable focus on quantifiable aspects that would otherwise be overlooked. These examples show that service provision depends on the *quantity* of the components, whether individuals in a population or species in an assemblage. It also depends on strategic delivery of the services: populations and species must have the right traits, and be in the right area at the right time in sufficient density. This is not to ignore the overall service that the host ecosystem also provides, which must always be borne in mind when focusing on ecology, rather than on the artificial compartment of a single taxon, such as the dragonflies.

9.5 Conclusions

The SPU/SAU concept is new and challenging. What it does above all is to enable us to think of nature's service provision in quantitative terms. It enables the construction of hypotheses about the role that *numbers* of individuals of particular species, at strategic or significant places or times, play in determining the *quality* of that provision. We can hypothesize that if the system is modified by a *certain* amount, that the *level* of provision will be altered accordingly and presumably predictably. Translated into human well-being, this means possible changes in quality of life.

Acknowledgements

We would like to thank Richard Harrington and Paula Harrison for critical comment. This work was supported by the RUBICODE Coordination Action Project (Rationalising Biodiversity Conservation in Dynamic Ecosystems) funded under the Sixth Framework Programme of the European Commission (contract no. 036890).

References

Aoki, T. (1997) Northward expansion of *Ictinogomphus pertinax* (Selys) in eastern Shikoku and western Kinki Districts, Japan (Anisoptera: Gomphidae). *Odonatologica* **26**, 121–133.

Asahina, S. (1974) The development of odonatology in the Far East. *Odonatologica* **3**, 5–12.

Bishop, J., Kapila, S., Hicks, F., and Mitchell, P. (2007) *Building Biodiversity Business: Report of a Scoping Study.* Shell International Limited and the World Conservation Union, London.

Bridle, J.R. and Vines, T.H. (2007) Limits to evolution at range margins: when and why does adaptation fail? *Trends in Ecology and Evolution* **22**, 140–147.

Clark, T.E. and Samways, M.J. (1996) Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. *Journal of Applied Ecology* **33**, 1001–1012.

Corbet, P.S. (2004) *Dragonflies: Behavior and Ecology of Odonata.* Comstock Publishing Associates, Cornell University Press, Ithaca, NY.

Grant, P.B.C. and Samways, M.J. (2007a) Montane refugia for endemic and Red Listed dragonflies in the Cape Floristic Region biodiversity hotspot. *Biodiversity and Conservation* **16**, 787–805.

Grant, P.B.C. and Samways, M.J. (2007b) Ectoparasitic mites infest common and widespread but not rare and Red Listed dragonfly species. *Odonatologica* **36**, 255–262.

Hardwicke, I. (1990) *Put a Little Dragonfly in your Life Today.* Letter to editor. *New York Times* 19 September.

Hassall, C., Thompson, D.J., French, G.C., and Harvey, I.F. (2007) Historical changes in the phenology of British Odonata are related to climate. *Global Change Biology* **13**, 1–9.

IUCN (2001) *IUCN Red List Categories, Version 3.1.* IUCN Species Survival Commission. IUCN, Gland.

Knight, T.M., McCoy, M.W., Chase, J.M., McCoy, K.A., and Holt, R.D. (2005) Trophic cascades across ecosystems. *Nature* **473**, 880–883.

Kritsky, G. and Cherry, R. (2000) *Insect Mythology.* Writers Club Press, Lincoln, NE.

Lemelin, R.H. (2008) Finding beauty in the dragon: the role of dragonflies in recreation and tourism. *Journal of Ecotourism*, in press.

Lockwood, J.A. (2001) The ethics of 'Classical' biological control and the value of place. In Lockwood, J.A., Howarth, F.G., and Purcell, M.F. (eds), *Importing Non-native Biological Control Agents (an International Perspective)*, pp. 100–119. Entomological Society of America, Lanham, MA.

Losey, J.E. and Vaughan, M. (2006) The economic value of ecological services provided by insects. *BioScience* **56**, 311–323.

Luck, G.W., Daily, G.C., and Ehrlich, P.R. (2003) Population diversity and ecosystem services. *Trends in Ecology and Evolution* **18**, 331–336.

Manning, G.S. and Lertprasert, P. (1973) Studies on the life cycle of *Phaneropsolus bonnei* and *Prosthodendrium molenkampi* in Thailand. *Annals of Tropical Medicine and Parasitology* **67**, 361–365.

McGeoch, M.A. (1998) The selection, testing and application of terrestrial insects as bioindicators. *Biological Reviews* **73**, 181–201.

Memmot, J. (2000) Food webs as a tool for studying non-target effects in biological control. In Follett, P.A. and Duan, J.J. (eds), *Nontarget effects of biological control*, pp. 147–163. Kluwer, Boston, MA.

Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Biodiversity Synthesis.* World Resources Institute, Washington DC.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A.B., and Kent J. (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858.

Naiman, R.J., Prieur-Richard, A.-H., Arthington, A., Dudgeon, D., Gessner, M.O., Kawabata, Z., Knowler, D., O'Keefe, J., Lévêque, C., Soto, D. *et al*. (2006) *Freshwater Biodiversity: Challenges for Freshwater Biodiversity Research*. Report no. 5. DIVERSITAS, Paris.

Nakao, S., Asahina, S., Miura, T., Wongsiri, T., Pangga, G.A., Lee, L.H.Y., and Yanao, K. (1976) The paddy field Odonata collected in Thailand, the Philippines and Hong Kong. *Kurume University Journal* **25**, 145–159.

Niba, A.S. and Samways, M.J. (2006) Development of the concept of 'core resident species' for quality assurance of an insect reserve. *Biodiversity and Conservation* **15**, 4181–4196.

Ott, J. (2007) The expansion of *Crocothemis erythraea* (Brullé, 1832) in Germany – an indicator of climate changes. In Tyagi, B.K. (ed.), *Biology of Dragonflies*, pp. 201–222. Scientific Publishers, Jodhpur.

Peters, G. (1988) Beobatchtungen an Aeshniden in Finnland (Odonata: Aeshnidae). *Opuscula Zoologica Fluminensia* **21**, 1–16.

Primack, R., Kobori, H., and Mori, S. (2005) Dragonfly pond restoration promotes conservation awareness in Japan. *Conservation Biology* **14**, 1553–1554.

Pritchard, G. (1964) The prey of adult dragonflies in northern Alberta. *Canadian Entomologist* **96**, 821–35.

Rahmel, U. and Ruf, A. (1994) Eine Feldmethode zum Nachweiss von anthropogen Stress auf natürliche Tierpopulationen: "fluctuating asymmetry." *Natur und Landschaft* **69**, 104–107.

Richardson, D.M. and van Wilgen, B.W. (2004) Invasive alien plants in South Africa: how well do we understand the ecological impacts? *South African Journal of Science* **100**, 45–52.

Rolston, III, H. (2000) The land ethic at the turn of the millennium. *Biodiversity and Conservation* **9**, 1045–1058.

Rosenberg, D.M. and Resh, V.H. (eds) (1993) *Freshwater Biomonitoring and Benthic Macroinvertebrates*. Chapman and Hall, New York.

Russell, R.W., May, M.L., Soltesz, K.L., and Fitzpatrick, J.W. (1998) Massive swarm migrations of dragonflies (Odonata) in eastern North America. *American Midland Naturalist* **140**, 325–342.

Sahlén, G. (2006) Specialists vs. generalists in the Odonata – the importance of forest environments in the formation of diverse species pools. In Cordero-Rivera, A. (ed.), *Forests and Dragonflies*, pp.153–179. Pensoft, Sophia.

Samways, M.J. (2006) Threat levels to odonate assemblages from invasive alien tree canopies. In Cordero-Rivera, A. (ed.), *Forests and Dragonflies*, pp. 209–224. Pensoft, Sophia.

Samways, M.J. (2007) Rescuing the extinction of experience. *Biodiversity and Conservation* **16**, 1995–1997.

Samways, M.J. and Taylor, S. (2004) Impacts of invasive alien plants on Red-Listed South African dragonflies (Odonata). *South African Journal of Science* **106**, 78–80.

Samways, M.J. and Grant, P. (2007) Honing Red List assessments of lesser-known taxa in biodiversity hotspots. *Biodiversity and Conservation* **16**, 2575–2586.

Samways, M.J., Taylor, S., and Tarboton, W. (2005) Extinction reprieve following alien removal. *Conservation Biology* **19**, 1329–1330.

Schilder, R.J. and Mardens, J.H. (2006) Metabolic syndrome and obesity in an insect. *Proceedings of the National Academy of Sciences USA* **103**, 18805–18809.

Sebastian, A., Thu, M.M., and Corbet, P.S. (1990) Suppression of *Aedes aegypti* (L.) (Diptera: Culicidae) using augmentative release of dragonfly larvae (Odonata: Libellulidae) with community participation in Yangon, Myanmar. *Bulletin of Entomological Research* **89**, 223–232.

Smith, B.P. (1988) Host-parasite interaction and impact of larval water mites on insects. *Annual Review of Entomology* **33**, 487–507.

Smith, J., Samways, M.J., and Taylor, S. (2007) Assessing riparian quality using two complementary sets as bioindicators. *Biodiversity Conservation* **16**, 2695–2713.

Stewart, D.A.B. and Samways, M.J. (1998) Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African savanna game reserve. *Conservation Biology* **12**, 683–692.

Street, P. (1976) *Animal Migration and Navigation*. David and Charles, Newton Abbott.

Suh, A.N. and Samways, M.J. (2001) Development of a dragonfly awareness trail in an African botanical garden. *Biological Conservation* **100**, 345–353.

Thompson, D.J., and Watts, P.C. (2006) The structure of the *Coenagrion mercuriale* populations in the New Forest, southern England. In Cordero-Rivera, A. (ed.), *Forests and Dragonflies*, pp. 239–258. Pensoft, Sophia.

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

Wikelski, M., Moskowitz, D., Adelman, J.S., Cochran, J., Wilcove, D.S., and May, M. (2006) Simple rules guide dragonfly migration. *Biology Letters* **2**, 325–329.

Willey, R.L., Bowen, W.R., and Eiler, H.O. (1970) Symbiosis between *Euglena* and damselfly nymphs is seasonal. *Science* **170**, 80–81.

Wright, M. (1944) Some random observations on dragonfly habits with notes on their predaciousness on bees. *Journal of the Tennessee Academy of Sciences* **18**, 172–196.